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Analyzing the effectiveness of using mixed-reality simulations to develop elementary pre-service teacher's high-leverage practices in a mathematics methods course

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Abstract

First-year elementary pre-service teachers usually conduct field observations but are barely offered opportunities to engage in well-structured teaching situations. In the current study, we implemented mixed-reality simulations (MRS) in a mathematics methods course to improve elementary pre-service teacher's abilities to elicit, question, and assess elementary students in an interview setting while the elementary students solve problem-solving activities. We answered the following questions: (i) To what extent do elementary pre-service teachers' exposure to MRSs enhance their use of productive mathematical talk moves (PMTMs) compared to other elementary pre-service teachers not exposed to the simulation; (ii) Do the numbers of MRS exposure improve elementary pre-service teacher's use of PMTM to elicit elementary students' thoughts? We found evidence that the use of MRS can effectively develop the teaching practices of first-year elementary pre-service teachers and that the number of simulations sessions play a relevant role in improving their teaching skills.

Keywords: elementary pre-service teacher, high-leverage practices, mixed-reality simulation, problem-solving, technology

INTRODUCTION

Pre-service teachers, in particular, elementary pre-service teachers (EPSTs), should be provided opportunities to develop and practice high-leverage teaching skills (Ball & Forzani, 2009; Ball et al., 2009). These opportunities must be provided before the EPSTs begin their clinical assignments or teaching responsibilities. In addition, ESTPs' opportunities to develop their teaching skills should occur in a safe and controlled environment where teaching anxiety is minimized, and teaching skills development is highlighted.

Many teacher education programs only require first-year ESTPs to complete field observations (Freeman, 2010), which in many cases fail to provide pre-service teachers opportunities to fully engage in the practice of teaching and to benefit from the interaction with students. Instead, they merely involve simple observations with little or no supervision or structure (Pomerance & Walsh, 2020). In addition, teacher preparation programs, in which preparation focuses on theories of teaching and learning, overlook the translation of concepts into the classroom practices (Ward et al., 2018). This leaves pre-service teachers under-prepared for successfully navigating the transition from theory to practice (Dalinger et al., 2020) during their later clinical field assignments or classroom teaching.

EPSTs should be taught how to foster practices through which their students discuss and externalize their ideas and rationale, and procedural fluency and conceptual understanding is developed (NCTM, 2014). Students most easily acquire these skills when teachers assess, elicit, and question them while working on problem-solving tasks where they must externalize their thought processes. Knowing how to successfully assess, question, and elicit an elementary student's understandings help teachers in making effective instructional changes (Stuhlman et al., 2009). However, to develop these skills, during the preparation time, EPSTs need opportunities to practice. These

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Contribution to the literature

- Because pre-service teachers are not usually offered teaching experiences during their first year of teaching preparation, this study becomes relevant by how pre-service teachers were expose to mixed-reality simulations in a mathematics methods course.
- We found evidence of how effective mixed-reality simulations are in supporting elementary pre-service teachers' preparation in assessing, questioning, and eliciting elementary students.
- Few studies have been conducted to find evidence that the use of mixed-reality simulations can enhance pre-service teachers' skills in using productive mathematical talk moves (PMTMs) with elementary students in problem-solving.

opportunities should happen throughout the whole program. One strategy for doing so is the implementation of simulation technologies (Dieker et al., 2014).

The use of simulation technologies in education has been evolving in recent years and has made it possible to implement technological tools that enhance pre-service teachers' skills. Mixed-reality simulation (MRS) is a simulation technology tool that provides a platform for participants—in this study, EPSTs—to develop high-leverage practices related to questioning, assessing, and eliciting students' thinking (Hatton et al., 2008), among other classroom teaching pedagogical skills (Hudson et al., 2019).

This study is relevant because we present results of a research, where we found evidence that validates the effectiveness of MRSs as an alternative teacher preparation tool. Using this tool develops EPSTs' ability to elicit students' mathematical knowledge and understanding through the implementation of PMTM (Chapin et al., 2009). We answer the following questions:

1. To what extent does EPSTs' exposure to MRSs enhance their use of PMTM, compared to EPSTs not exposed to the simulation;
2. Does the number of MRSs sessions exposure (one or more than one repetition) improve elementary pre-service teacher's use of PMTM to assess, question, and elicit elementary students' thoughts?

THEORETICAL PERSPECTIVES

Using technology in education opens a full new set of opportunities and possibilities for preparing pre-service teachers for classroom teaching. In particular, MRSs examined in this study helped approximate classroom teaching by implementing high-leverage practices that support pre-service teachers' acquisition of teaching skills.

As mentioned, MRSs provide a space for EPSTs to enhance their abilities to question, assess, and elicit students' mathematics thinking. Murphy et al. (2021) characterize MRS as a learning method categorized as situated learning (Lave & Wenger, 1991). That is to say, learning occurs as result of social interactions and "between individuals and materials in authentic contexts" (Lave & Wenger, 1991, p. 32). According to the theory of situated learning (Cobb & Bowers, 1999; Lave & Wenger, 1991), the transfer and acquisition of knowledge by teachers and students alike are subjected to how those interactions align, and it is, therefore, essential in pre-service teacher preparation to simulate situated learning conditions as similar as possible to real-life situations.

MRSs support the above by allowing the implementation of educational scenarios for the preparation of pre-service teachers—in this case, EPSTs. Two common MRS technologies platforms are Mursion and TeachLivE (Hudson et al., 2019); in both, participants (e.g. EPSTs) interact in real-time with computer avatars that simulate a diverse set of students with a varied of backgrounds, personalities, and attitudes in a classroom-type setting. An educational simulation specialist works to combine the human factor with artificial intelligence (Murphy et al., 2021), controlling the speech, movement, and behavioral level of the avatar in order to provide a realistic experience for EPSTs (Dieker et al., 2014). The interaction between the EPST and the avatar—in reality, is an interaction with the educational specialist—follows a structured developed teaching situation. These situations are not only controlled but can be repeated as many times as necessary to develop teaching skills, an aspect that can hardly be achieved in a real classroom setting.

Approximation of Practice Through Mixed-Reality Simulations

MRSs is an alternative preparation tool intended to provide EPSTs opportunities to develop teaching skills similar to real-life classroom situations/practices. The goal is that first or second-year EPSTs be provided with approximations of practices that simulate experiences they would not otherwise have until meeting their clinical teaching field requirements. In addition, to introduce the EPSTs to more authentic teaching experiences earlier in their preparation. Krause et al. (2020) define approximation of practice as ways for enacting and experimenting around aspects or situations related to the practice of teaching. Grosman et al. (2009a, 2009b) define approximations of practice as opportunities for pre-service teachers—in this case EPSTs—"to engage in practices that are more or less proximal to the practices of a profession" (p. 2056). Through MRSs, EPSTs have opportunities to practice and develop high-leverage skills (Ball et al., 2009) in a safe and controlled environment. EPSTs would not have occasions to develop their teaching skills by only conducting field observations, for which, in many cases, they are only placed in passive roles with "little or no structure that would facilitate [the] learning of effective teaching practices" (Dalinger et al., 2020, p. 11).

In this project, we offered EPSTs an approximation of practice through MRSs with the possibility of having as many as needed repeated interactions to "gain facility and fluidity with [productive mathematical] teaching moves" (Krause et al., 2020, p. 3).

High-Leverages Practices and Development with Mixed-Reality Simulations

Quality in teaching is critical when fostering students' conceptual understandings, critical thinking, reflection, and effective collaboration (NCTM, 2014). These skills can be achieved when teachers implement high leverage practices (Ball et al., 2009), proven to be effective teaching approaches (Qi & Sykes, 2016). High leverage practices (HLPs) like eliciting, questioning, and assessing—among many others similar teaching practices—are essential to help and support students' knowledge acquisition. Prominent researchers from TeachingWorks (2016) support the above and state that HLPs are "the basic fundamental of teaching" (para. 1). Ball et al. (2009) and Grossman et al. (2009a) also show that HLPs potentially develop students' learning acquisition and their motivation toward particular subjects (e.g., mathematics or science). Furthermore, they argue that HLPs can be implemented as part of teacher programs to prepare pre-service teachers—in elementary or secondary programs—on how to teach. For example, EPSTs can be trained and prepared in the use of PMTM (Chapin et al., 2009) as pedagogical moves to effectively elicit, question, and assess elementary student's understanding of mathematical concepts, and to successfully orchestrate productive mathematical discourse in the classroom (Stein et al., 2015). Chapin et al. (2009) define PMTM as effective strategies and actions toward "making progress [in] achieving instructional goals [that] support [and advance students'] mathematical thinking and learning" (p. 11).

Unfortunately, preparing EPSTs for the use and implementation of high leverage practices requires time, rehearsals, and a well-structured partnership with school districts. Frequently, teacher preparation programs offer EPSTs the opportunity to develop HLPs during their student clinical teaching assignments, which normally occur during the last semester or year of the teacher preparation program. However, first year EPSTs are commonly only required to conduct classroom observations without a structured program through which they can practice and develop HLP skills.

MRSs can close the gap in teaching practices between first-and last-year EPSTs. First-year EPSTs can be exposed to MRSs to practice HLPs in a safe, controlled environment with a structured program that enhances and fosters the development of teaching instructional skills like PMTMs (Dieker et al., 2017). Combining MRSs and HLPs help teacher educators to better "contextualize the comprehensions of how to teach" (Gundel et al., 2019, p. 249), especially when preparing first-year EPSTs. Likewise, MRSs can also be implemented to enrich teaching practices among in-service teachers (Mursion, 2016).

Transfer of Learning Through Simulation Technologies

Transfer of learning is the capacity of an individual to use and implement knowledge learned previously in a new situation (Dalinger et al., 2020), meaning the individual can demonstrate prior learning at a later time (Perkins & Salomon, 1992). Therefore, when new knowledge is used to solve a problem in a context that is unknown to the individual, the application and transfer of the learned knowledge becomes evident (Cook et al., 2007).

Perkins and Salomon (1992) assert that the transfer of learning occurs when individuals are exposed to "thorough and diverse practice" (p. 6), which is the approach we followed in this study. In the context of education, particularly in the context of this study with elementary pre-service teachers, the transfer of learning requires several phases for the transfer process to be successful. First, the learner (i.e., elementary pre-service teachers) needs to be exposed to the new knowledge. Second, the learner must have several opportunities to practice and develop the skills of the newly learned knowledge in a context that promotes and motivates the learning. Finally, the learner must reflect on the importance and implications of the newly learned knowledge (Mayer et al., 2011).

For an individual to be able to transfer knowledge (in the particular context of this study, with EPSTs), the new knowledge would have to be learned as outlined above. Here, EPSTs are systematically prepared in theories and concepts on how to assess, elicit, and question elementary students within the context of problem-solving activities in a classroom setting. They later are exposed to MRSs, where they depict evidence of having transferred the learning. Further, they interact with an elementary student in the form of a clinical practice where the transfer of learning is depicted.

According to Dieker et al. (2014) EPSTs who have practiced teaching skills with MRSs, will later successfully transfer those skills and knowledge into the real classroom. Similarly, Garland and Garland (2020) and Sander (2014) found evidence that EPSTs who were exposed to MRSs to develop HLPs skills, were able to demonstrate that what they had learned in the classroom and through the MRSs were useful pedagogical strategies for their field teaching experiences.

Mursion Technology as a Mixed-Reality Simulation Software in Education

The use of technologies in education has evolved in recent years (Martín-Gutiérrez et al., 2017) with different applications used to enhance the learning experience and knowledge acquisition of students and for the preparation of pre-service teachers or professional development of in-service teachers. One type of application that has been growing in popularity—for its flexibility—within teacher preparation programs is MRS. In particular, we refer to the MRS software developed by Mursion® (2016), which was used and implemented in this study to provide EPSTs with opportunities to engage in authentic teaching practices.

Mursion (2016) MRS is an effective technological tool to be used with EPSTs because it effectively simulates an elementary classroom with a set of diverse students (Murphy et al., 2021). Mursion's (2016) MRS can simulate a wide range of students' behaviors, same as it would happen in a real classroom, but without the risk that potentially occurs when interacting with young students. The fact that Mursion (2016) integrates reality with artificial intelligence, allows for the learner—in this case EPSTs—to experience, practice, and develop teaching skills as if they were in a real-life situation; this is significant due to the difficulties in replicating the numerous unpredictable and uncontrollable variables that take place in a real classroom (Murphy et al., 2021). Participants are exposed to MRS––in particular Mursion (2016)—through a video platform (e.g., Zoom). As explained above, what participants—i.e., EPSTs—see through their computer monitors or laptop screens is a real-time, live computer avatar controlled by an experienced educational-technology MRSs specialist (Gagneré & Plessiet, 2018), who interacts with the participant and responds as a real elementary student, providing a level of authenticity (Dalinger et al., 2020) and encouraging the participant to fully engage in that interaction as they would do in a real classroom. The educational-technology MRS specialist follows a structured, previously developed lesson about the topic or task that is addressed in the simulation, or that is desired to be developed for the participants, which in the case of this study were high-leverage practices (Ball et al., 2009) related to eliciting, assessing, and questioning elementary students. It is important to mention that although the educational-technology MRS specialists follows a pre-developed lesson that highlights the hits and misses of the participants in relation to the topic being practiced, the interaction is not linear, but instead flexible and adaptable depending of the responses, attitude, and behavior of the participant. This non-linearity was particularly useful in the context of this study, since participants were EPSTs in their first or second year of the educational program who had many skills yet to learn, practice, and develop.

The fact that Mursion (2016) provides a flexible way to interact with the MRSs' participant, allows for multiple repetitions whenever the participant needed them, a concern arose, the simulation need to be stopped, or when the desired skill needed continued practice (Hudson et al., 2019). These are almost impossible situations to achieve in a real classroom setting due to the uncontrollable variables. Ultimately, our intention here was to provide the participants of this study—i.e., EPSTs—an approximation of the teacher practice (Grossman et al., 2009a, 2009b) in a safe, controlled environment, as real as possible, with the intention of developing and enhancing their teaching skills.

METHODOLOGY, DATA COLLECTION, AND PARTICIPANTS

The study presented here corresponds to the second phase of a larger study. The first phase was conducted during the Spring 2018, from which the findings have already been reported (Aguilar & Telese, 2018). However, to better inform the reader, we are detailing here the methodology followed in both phases. This is relevant in order to answer one of the research questions related to the effect of the number of simulations on the EPSTs' use of PMTMs. In addition, it is relevant to mention that the main difference between the two phases was the number of MRS sessions exposure. Specifically, there was only one simulation session during the first phase, while in the second, there were three.

We took a qualitative approach (Mills & Birks, 2014) considering a deductive coding process (Miles et al., 2018; Saldaña, 2021) guided by an adapted coding scheme that emphases a classroom's high-leverage practices, like PMTM (Chapin et al., 2009; Ginsburg, 1997; Jacob & Empson, 2016; Moyer & Milewicz, 2002). The PMTM depicted in **Table 1** were considered when analyzing the interaction of EPSTs with an elementary student.

Participants of this second phase of the study were 40 EPSTs in their first or second year of a teacher preparation program in a four-year public institution located in the south-central region of the United States. All the EPSTs have already taken the mathematics sequence courses (i.e., college algebra and fundamentals of mathematics I & II).

The EPSTs were evenly divided in two sections, while taking a mathematics methods course during Fall 2019. The target population was composed of 93% females and 6% males. All the EPSTs have identified themselves as Hispanics, and their age ranges from 20 to 26 years old.

Table 1. Mathematical talk moves coding scheme system

Code	Move type	Characteristic
Ra	Rapport	Building a connection with the student
RP	Initial unpacking	Reading the problem
R_V	Revoicing	Paraphrasing to verify a statement
R_E	Repeating	A repetition of the original question
RPe	Repeating with modifications	Repetition of the task using a different context or set of numbers.
Un	Unpacking	Ensuring the child is making sense of the story problem.
E	Elaborating	Request to add, elaborate or explain a response It includes encouraging the child to consider other strategies
E_F	Elaborating-follow-up	Following up a previous response
L	Leading	Instructing no eliciting
W	Waiting	Allowing time in silence
N	No question	No question or move at all
LOQ	Low-order-question	No reasoning is encouraged, simple question
NC	No category	Other

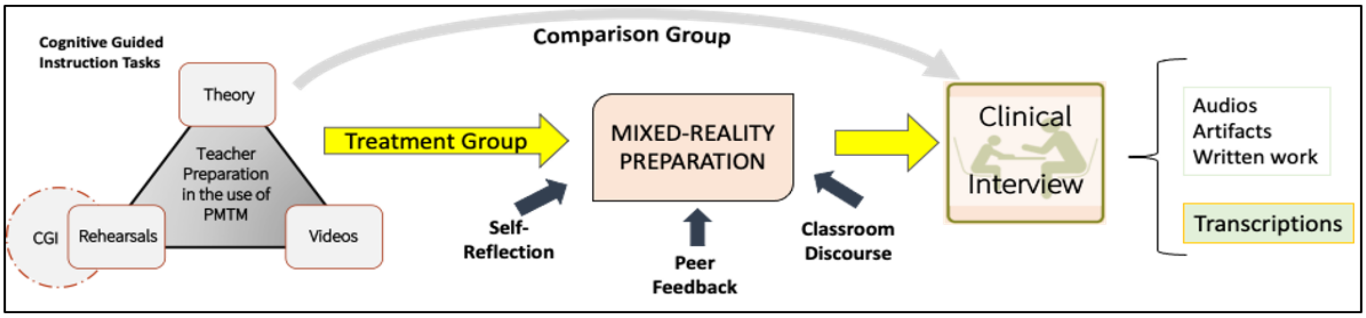

Figure 1. Visual representation of the methodology

As part of the course, all the EPSTs were required to conduct a clinical interview (Ginsburg, 1997; Zhou, 2011) with an elementary student. The intention of the assignment was for the EPSTs to practice how to access, elicit, and question an elementary student when solving a mathematical task. The tasks followed the cognitively guided instruction's framework of Carpenter et al. (2014). To conduct the clinical interview, the EPSTs were provided with a structured guideline on how to conduct the interview. This included six previously developed mathematical tasks that the EPSTs were asked to use during the interview.

To prepare the EPSTs for the assignment, both the comparison and treatment group were required to participate in group discussions about readings and theoretical concepts of high-leverage practices, class rehearsals (Horn, 2010) simulating an elementary classroom, and analyze and reflect on teaching videos (see **Figure 1** for a visual representation of the methodology).

The class rehearsals were purposefully designed for the EPSTs to practice how to assess, question, and elicit an elementary student while solving a mathematical task. During the course, the class rehearsals were implemented every other week. For this purpose, the EPSTs were asked to form groups of four or five members, where each member had a different role (e.g., teacher or elementary student), while the rest of the class observed. Once the rehearsal was over, a whole-class discourse was orchestrated to highlight the "*hits and misses*" and reflect on how to improve eliciting and assessing an elementary student. In total, all the EPSTs spent approximately four hundred minutes practicing and developing high-leverage practices related questioning, assessing, and eliciting elementary students' thoughts.

Once all the EPSTs were prepared in class for the clinical interview, one section (i.e., the comparison group) continued rehearsing in class as part of the course instruction, which included engaging in small groups and whole-class discussions, reflections, and feedback. The other section (i.e., the treatment group) were exposed to MRSs. In the simulations, the EPSTs interacted with a set of elementary avatar students controlled by an educational simulation specialist (**Figure 2**).

Through the MRS, the EPSTs practiced how to assess, question, and elicit an elementary student's rationale and understanding of mathematics in a problem-solving task, comparable to what occurred in the class-rehearsals. It is relevant to mention that because both sections (i.e., the comparison and treatment group) were attending the mathematics methods course (which is a required course in the teacher preparation program), and the clinical interview was part of the course assignments, all the EPTSs participated and completed the study. No extra credits or benefits were offered to either section.

Figure 2. Example of MRS session

Similar to the clinical interview assignment mentioned above, the tasks implemented during the MRSs were of the cognitive guided instruction type (Carpenter et al., 2014) and covered several elementary mathematics concepts (e.g., join or separate-change unknown, measurement or partitive division).

In total the EPSTs (i.e., treatment-group) experienced three sessions that lasted between 8-12 minutes each. In addition, the EPSTs were required to write a short self-reflection essay related to their experience, participate in whole-class discussions about the experience, and provide critical peer feedback within small teams. The teams were randomly created with three or four members each.

After the clinical interview, all the EPSTs (i.e., both in the comparison and treatment group) provided transcriptions of their interaction with the elementary student—among other data that were not reported here (e.g., audios, student's work, and artifacts). However, the transcripts were compared with the audio to confirm the accuracy of transcripts. Each audio lasted between 20 and 30 minutes depending on how many PMTMs the EPSTs decided to use. We coded and analyzed the transcriptions independently (see the transcript 1 for an example of the coding process) following coding scheme system described in **Table 1**. The codes are shown in parenthesis.

Transcript 1

1. EPST: Ok, next problem. Maria's dad baked pizzas to celebrate her birthday. He baked 4 small pizzas not knowing that 6 friends would show up for the party. How much pizza each friend of Maria will get? [RP]
2. Student: [Got pencil and started solving it. He took about 3 minutes to solve the problem and get an answer] [W]
3. EPST: You're done? [NC]
4. Student: (Nodded yes)
5. EPST: Ok, so what's your answer? [LOQ]
6. Student: 5…the 6 friends get 5 slices each.
7. EPST: Ok so each friend, each of the 6 friends get 5 pizzas each. So, is it 5 slices? Can you explain to me here what you did with the circles? [Rv, E]
8. Student: Each slice I have to put it in a friend.
9. EPST: Ok so each circle you cut it up as if it were an actual pizza and you put each slice into these circles. What do these circles represent? Because you did six of them. [Ef]
10. Student: The 6 friends.
11. EPST: Oh, ok the 6 friends, and then you divided them up and then you just counted the number of slices each friend got? [Rv]
12. Student: Mhm
13. EPST: Ok, do you think or know you can solve it another way? [E]
14. Student: (Nodded no)
15. EPST: This is the only way you know? [LOQ]
16. Student: (Nodded yes)
17. EPST: Ok, what if you consider that each small pizza has 4 slices, then if you multiply 4×4, that will give you 16 slices. Now if you divide 16 by all the friends that showed up to the party… 6, each friend will get about 16/6, which is 2 slices, and there will be 4 left…[L]
18. EPST: Ok. That's good, lets stop here. We are done. Thank you!

Before coding the transcripts, we went through a calibration process (Bol & Hacker, 2012) with the intention of minimizing our differences during the coding process. After resolving our differences, we obtained a final interrater agreement (O'Connor & Joffe, 2020; Tinsley & Weiss, 2000) of approximately ninety-one percent. This was obtained by comparing and discussing each of our codes, for which we provided our rationale when differences emerged. This was a time-consuming but necessary step in order to be as accurate as possible.

Table 2. Frequencies of productive mathematical talk moves codes

Code	Move	Comparison group (No MRS)	Treatment group (Exposure to MRS)
Ra	Rapport	6	10
RP	Initial unpacking	115	120
RV	Revoicing	43	124
Re	Repeating	62	105
Rpe	Repeating with different numbers or context	7	19
Un	Unpacking	8	28
E	Elaborating	107	168
Ef	Elaborating/Follow-up	29	66
L	Leading	51	113
W	Waiting	59	118
N	No question	17	5
LOQ	Low-order-question	121	129
NC	No category	36	21
Total moves		**661**	**1,026**

FINDINGS AND RESULTS

The EPSTs were prepared as part of a mathematics methods course on how to assess, elicit, and question elementary students using high-leverage practices (Ball et al., 2009) in the context of problem-solving activities. All the EPSTs received some preparation in a simulated way; the comparison group, by engaging in several classroom rehearsals (Horn, 2010; Ward et al., 2018), and the treatment group by being exposed to MRSs. In either case (i.e., the treatment or comparison group), we intended to provide the EPSTs with an approximation of practice (Grossman et al., 2009b) of the experience they will face during their teaching responsibilities.

As mentioned above, we coded and analyzed the transcriptions of the clinical interviews. Later we compared and contrasted the differences within the comparison and treatment group. In **Table 2**, we show a comparison of the frequency of the results obtained after the transcripts were coded and analyzed.

In general, the EPSTs exposed to the state-of-the-art technology MRS implemented 55% more PMTMs than the EPSTs who were not exposed to MRS. They were also more open to building rapport with their elementary student, which is essential when looking to engage students in a topic or discussion (Starcher, 2011). In addition, EPSTs exposed to MRS depicted a higher use of PMTMs when revoicing, repeating, repeating in a different context, unpacking, elaborating/follow-up, waiting, and leading.

Revoicing is the move in which teachers repeat what the student has said (Chapin et al., 2009; Ferris, 2014), to confirm, understand, clarify what the student is implying, or simply to help the student reflect on what was just said. In addition, it provides teachers the opportunity to model mathematical academic language. For example, we depict (see transcript 2 in the following) an excerpt of one interview an EPST had with an elementary student.

Transcript 2

EPST: …but can you please explain how you know that?

Student: well, I know that 3 and 2 is 5, and double is 12.

EPST: so, what you are saying is that three times two is five?

Student: oh, no, no… I meant, 3 times 2 is 6, and double 6 is 12.

EPSTs exposed to MRSs implemented the revoicing move 124 times, meaning that they used this move almost three times more than their peers who were not exposed to MRSs. Using the revoicing move when orchestrating a whole class discussion or in a clinical setting interview is vital for teachers to enhance student's self-reflection about their own thinking, help other students follow the interaction that is taking place, or help students externalize their thoughts (Lesh & Doerr, 2003). Similarly, EPSTs exposed to MRSs tended to repeat the questions more often than their peers who were not exposed to MRS.

According to our findings, the difference between the treatment (MRS exposure) and the control group (No MRS) was almost double. However, what it is notable, is that EPSTs exposed to MRS decided in more instances to adjust the context of the problem in order to help their elementary student have a better understanding of the mathematical task being presented. This is relevant since it highlights a desire from the EPSTs exposed to MRS to further the elementary student's problem understanding (Boaler, 2015), which transforms into gaining motivation and engagement toward the mathematical task being solved.

Another PMTM used by the EPSTs was unpacking (Kajander, 2007). *Unpacking* refers to the action of teachers to break down the problem or task presented to the student to motivate and enhance their interest, and to help them make connections with the context of the problem and the ideas being taught. EPSTs exposed to MRSs engaged in the use of unpacking approximately three times more than those not exposed to MRS. Making sure students have a full understanding of what they have to do and the context of the problem, is essential to successfully motivate and engage them in developing strategies for solving the mathematical task (see example in transcript 3). It is not clear why the EPSTs not exposed to MRSs seldom decided to unpack the problem to the elementary students, but it can be assumed that either the elementary students completely understood the problem in most of the cases, or that the EPSTs hadn't realized how relevant the unpacking move is. What is a fact being that the implementation of MRSs positively affected the EPST's understanding of the unpacking move?

Transcript 3

EPST: [reading the problem] David made tamales for all his friends. He made 29 tamales. 13 of the tamales were rajas con queso and the rest were beef. How many beef tamales did David make?

Student: mmm... what are "rajas con queso"?

EPST: the "rajas" refer to a type of chile called "poblano". Do you like spicy food?

Student: yes!

EPST: Have you seem a Jalapeno chile?

Student: yes, my dad cooks them all the time in the grill.

EPST: ahh, muy rico! Well, the Poblano chile, is like a Jalapeno, but bigger. People clean it by taking out the seeds, and later cook it with cream cheese.

The EPSTs used the move "*elaborating*" (Chapin et al., 2009) to request the students to further their rationale about their solutions and explanations by adding, elaborating, and encouraging the student to consider other strategies (Jacobs & Empson, 2016), or by following a previous idea (see transcript 1). Similarly, to other productive moves, EPSTs exposed to MRS demonstrated nearly 2.5 times more occasions in which they considered using this move, in comparison to the EPSTs not exposed to MRS. Requesting students to add more into what they have already done is an important and necessary move that is often used in classroom mathematical discourse (Drageset, 2015). The fact that EPSTs exposed to MRSs used this productive move at a greater frequency than their peers not exposed to MRS might be because, through the use of MRS, EPSTs realized the necessity of furthering their student's thoughts and big ideas, and that eliciting is a relevant teaching skill that, when used in a classroom setting or in a clinical interview (as is the case in this report), can help students externalize their rationale (Lesh & Doeer, 2003).

One of the PMTMs that is as relevant as the others but does not actually require the teacher to engage in any teaching action is the "*waiting*" move (Ginsburg, 1997). In transcript 1, we depict an example of this move, where the EPST allows time for the elementary student to solve the task. Although this move requires teachers to allow time in silence until the students have entirely solved the mathematical task, it was not implemented by the EPSTs not exposed to MRS (i.e. comparison group) as much as those exposed to MRSs. The art of listening (Van Blankenstein et al., 2011) is a relevant skill that, when used well, not only allows the teacher to follow what the student is saying, doing, and externalizing, but would help the teacher to assess and elicit the students' solutions accordingly, and promote discourse among the students in a whole-class discussion.

EPSTs exposed to MRS had a tendency of instructing their students—as depicted in transcript 1—instead of eliciting, assessing, and questioning them, as can be seen in the leading move (see **Table 2**).

EPSTs exposed to MRS lead their students almost twice as often the time in comparison to EPSTs not exposed to MRS. The opportunity to practice with the simulation helped develop the confidence teaching skills of the EPSTs to the point of leading instead of assessing, questioning, and eliciting (Aguilar & Telese, 2018). However, as Aguilar and Telese (2018) stated, this does not represent "an indication of mastering the skills of productive mathematical talk moves" (para. 10). Further research is needed to assess how and why MRSs develop the EPSTs' confidence. Similarly, we noticed that the EPSTs highly engaged in low-ordered questioning (LOQ), which could be considered as a non-productive mathematical move. Same as above, further research will be needed to explore why the EPTSs ask questions that do not elicit the student's thoughts.

Comparison Between Simulation Exposure

The findings presented here are part of a second phase of a larger study, where EPSTs were exposed to MRS within a mathematics methods course in a teacher preparation program.

During the study's first phase (Aguilar & Telese, 2018), which was implemented in Spring 2018 following the same methodology, 50 EPSTs took the math methods course. Similar to the participants of this study, the EPSTs were evenly divided in two groups: One, the comparison group (i.e., not exposed to MRS), and the other the treatment group (i.e., exposed to MRS). Likewise, to conduct the clinical interview with an

Table 3. Comparing number of mixed-reality simulation within treatment groups

		MRS exposure	
		Three simulations (%)	One simulation (%)
RV	Revoicing	15	13
Re	Repeating	12	4
E	Elaborating	21	20
Ef	Elab/Follow-up	9	7
L	Leading	13	22
W	Waiting	14	4
N	No question	1	0
LOQ	Low-order-question	14	27
NC	No category	1	4

elementary student, both sections were prepared in class (i.e., having classroom discussions of the readings and theories, participating in teaching rehearsals, and reflecting).

The main difference between the first and the second phase was that during the first phase the treatment group was only exposed one time to a MRS session that lasted between 7-10 minutes. In contrast, in the study presented here, we report the findings of EPSTs exposed three times to MRSs. After comparing the treatment and control groups within the study's second phase, we now present the comparison and differences between the first and second phases of both treatment groups.

By comparing the treatment groups of both phases, we noticed (see **Table 3**), that the number of MRS sessions an EPST is exposed to can potentially influence how the EPSTs use and implement PMTMs when conducting a clinical interview. Exposure to MRS successfully supports the transfer of learning and knowledge acquisition. It can be inferred that these students will also use these pedagogical strategies once they start their educational journey.

The EPSTs who were exposed three times to MRSs displayed a higher percentage use of almost all the PMTMs, except the "leading" teaching move. We found evidence that increasing the number of simulations positively helped EPSTs' reflect on their instruction and the type of teaching mathematical talk moves they would implement when either conducting a clinical interview or orchestrating a classroom discourse.

From **Table 3**, we noticed that the implementation of MRSs in a mathematics methods course during teacher preparation provided the EPSTs an opportunity to develop high-leverage teaching skills. As mentioned above, increasing the number of simulations exposure plays a relevant role in developing and enhancing EPSTs' skills in ways that foster PMTMs to assess, elicit, and question their students in a formative approach. We also found evidence that increasing the number of MRS sessions develops the EPST's sense that it is important to use more higher-order questions; however, this requires further study.

CONCLUSIONS

Comparisons were made between one group of EPSTs exposed to MRSs and another group not exposed to simulations in a mathematics methods course. Based on our findings, it can be inferred that the use of technologies like the one implemented in this study can enhance the development of high-leverage teaching practices (Ball et al., 2009). However, the use of MRSs was not intended to replace real teaching experience, only to provide EPSTs an approximation of the actual practice of teaching (Grosman et al., 2009a). This is typically limited for first-year pre-service teachers in most teacher education programs, which only require EPSTs to complete field observations (Freeman, 2010).

We found that EPSTs who received enhanced preparation with MRS displayed a stronger use of PMTM (Chapin et al., 2009) to assess, elicit, and question elementary students when solving mathematical tasks during a clinical interview. EPSTs exposed to MRS were more enthusiastic in the use of PMTMs during their interaction with the elementary students and are probably more likely to use those skills during their clinical teaching assignments or future teacher responsibilities. Nevertheless, these are areas of research that will need to be further developed and considered.

Although MRSs enhance the learning of teaching skills, they do not help much in developing EPSTs' anticipations of using low-level cognitive questions (Wimer et al., 2001) as part of their interaction with elementary students. More class discussions and reflections about the topic might likely be needed, and perhaps more MRS sessions are necessary. In any case, the above needs to be further studied, and evidence is needed on better preparing EPSTs by asking more higher-order questions and avoiding lower-level questions, which is not uncommon in elementary classrooms' discourse (Shahrill & Mundia, 2014; Wilkinson & Martino, 1993).

Regarding the number of MRS sessions that would make a difference in the preparation of EPSTs, our evidence indicates that a single MRS session would not be sufficient. Several structured MRSs session are necessary to advance the participants' teaching skills effectively.

Teacher preparation programs are not only required to provide pre-service teachers adequately well-structured teaching practices, but despite how long they are, they must be of the highest quality, focus, and aim to develop the necessary skills the pre-service teacher will need for their future responsibilities (Pomerance & Walsh, 2020). The use of MRSs, although not perfect, is an opportunity for teacher preparation programs to better prepare pre-service teachers—working at any grade level—before they are ready to have a real interaction with students. In particular, EPSTs in their first years of the teacher preparation program could potentially benefit most through being exposed to MRSs in a safe, controlled, and structured environment (Dieker et al, 2014, 2017), where teaching imprecisions can be corrected and improved, and where the EPSTs can be allowed multiple repeated practices with different controlled challenge levels, can receive feedback, and reflect about their teaching. For example, an instructor could guide EPSTs to reflect on the tendency to lead a student at a moment that instead requires eliciting, assessing, and questioning.

In this report, we have provided evidence that the implementation of MRSs positively fosters the development of teaching skills like PMTMs, and that the number of MRS sessions correlates with the development of high-leverage practices.

Finally, we will continue conducting studies in which we will increase the number of MRSs sessions as a way to further develop the teaching skills and practices of EPSTs, and will include a more focused and controlled coaching and feedback process for EPSTs.

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REFERENCES

Aguilar, J. J., & Telese, J. A. (2018). The implementation of mixed-reality simulations: An innovative approach to train first-year pre-service elementary mathematics teachers. *Association of Mathematics Teacher Educators: Connections*. https://amte.net/connections/2018/12/implementation-mixed-reality-simulations-innovative-approach-train-first-year

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. https://doi.org/10.1177/0022487109348479

Ball, D. L., Sleep, L., Boerst, T., & Bass, H. (2009). Combining the development of practice and the practice of development in teacher education. *Elementary School Journal*, *109*(5), 458-474. https://doi.org/10.1086/596996

Boaler, J. (2015). *Mathematical mindsets: Unleashing students' potential through creative math, inspiring messages and innovative teaching*. John Wiley & Sons.

Bol, L., & Hacker, D. J. (2012). Calibration research: Where do we go from here? *Frontiers in Psychology*, *3*, 229. https://doi.org/10.3389/fpsyg.2012.00229

Carpenter, T., Fennema, E., Franke, M. L., Levi, L., & Empson, S. B. (2014). *Children's mathematics, second edition: Cognitively guided instruction*. Heinemann.

Chapin, S. H., O'Connor, C., O'Connor, M. C., & Anderson, N. C. (2009). *Classroom discussions: Using math talk to help students learn, grades K-6*. Math Solutions.

Cobb, P., & Bowers, J. (1999). Cognitive and situated learning perspectives in theory and practice. *Educational Researcher*, *28*(2), 4-15. https://doi.org/10.3102/0013189X028002004

Cook, D. J., Holder, L. B., & Youngblood, G. M. (2007). Graph-based analysis of human transfer learning using a game testbed. *IEEE Transactions on Knowledge and Data Engineering*, *19*(11), 1465-1478. https://doi.org/10.1109/TKDE.2007.190634

Dalinger, T., Thomas, K. B., Stansberry, S., & Xiu, Y. (2020). A mixed reality simulation offers strategic practice for pre-service teachers. *Computers & Education*, *144*, 103696. https://doi.org/10.1016/j.compedu.2019.103696

Dieker, L. A., Hughes, C. E., Hynes, M. C., & Straub, C. (2017). Using simulated virtual environments to improve teacher performance. *School-University Partnerships*, *10*(3), 62-81.

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.

Drageset, O. G. (2015). Student and teacher interventions: a framework for analysing mathematical discourse in the classroom. *Journal of Mathematics Teacher Education*, *18*(3), 253-272. https://doi.org/10.1007/s10857-014-9280-9

Ferris, S. J. (2014). Revoicing: A tool to engage all learners in academic conversations. *The Reading Teacher*, *67*(5), 353-357. https://doi.org/10.1002/trtr.1220

Freeman, G. G. (2010). Strategies for successful early field experiences in a teacher education program. *SRATE Journal*, *19*(1), 15-21.

Gagneré, G., & Plessiet, C. (2018, June). Experiencing avatar direction in low cost theatrical mixed reality setup. In *Proceedings of the 5th International Conference on Movement and Computing* (pp. 1-6). https://doi.org/10.1145/3212721.3212892

Garland, K. V., & Garland, D. (2020). TeachLivE™ and teach well: Simulations in teacher education. In E. Bradley (Ed.), *Games and simulations in teacher education* (pp. 183-195). Springer, Cham. https://doi.org/10.1007/978-3-030-44526-3_13

Ginsburg, H. (1997). *Entering the child's mind: The clinical interview in psychological research and practice*. Cambridge University Press. https://doi.org/10.1017/CBO9780511527777

Grossman, P., Compton, C., Igra, D., Ronfeldt, M., Shahan, E., & Williamson, P. (2009a). Teaching practice: A cross-professional perspective. *Teachers College Record*, *111*(9), 2055-2100. https://doi.org/10.1177/016146810911100905

Grossman, P., Hammerness, K., & McDonald, M. (2009b). Redefining teaching, re-imagining teacher education. *Teachers and Teaching: Theory and Practice*, *15*(2), 273-289. https://doi.org/10.1080/13540600902875340

Gundel, E., Piro, J. S., Straub, C., & Smith, K. (2019). Self-efficacy in mixed reality simulations: Implications for preservice teacher education. *The Teacher Educator*, *54*(3), 244-269. https://doi.org/10.1080/08878730.2019.1591560

Hatton, S., Birchfield, D., & Megowan-Romanowicz, M. C. (2008, August). Learning metaphor through mixed-reality game design and game play. In *Proceedings of the 2008 ACM SIGGRAPH symposium on Video games* (pp. 67-74).

Horn, I. S. (2010). Teaching replays, teaching rehearsals, and re-visions of practice: Learning from colleagues in a mathematics teacher community. *Teachers College Record*, *112*(1), 225-259. https://doi.org/10.1177/016146811011200109

Hudson, M. E., Voytecki, K. S., Owens, T. L., & Zhang, G. (2019). Preservice teacher experiences implementing classroom management practices through mixed-reality simulations. *Rural Special Education Quarterly*, *38*(2), 79-94. https://doi.org/10.1177/8756870519841421

Jacobs, V. R., & Empson, S. B. (2016). Responding to children's mathematical thinking in the moment: An emerging framework of teaching moves. *Zentralblatt fur̈ Didaktik der Mathematik* [*Central Journal for Didactics of Mathematics*], *48*(1), 185-197. https://doi.org/10.1007/s11858-015-0717-0

Kajander, A. (2007). Unpacking mathematics for teaching: A study of preservice elementary teachers' evolving mathematical understandings and beliefs. *Journal of Teaching and Learning*, *5*(1), 33-54. https://doi.org/10.22329/jtl.v5i1.127

Krause, G., Silva, J., & Aguilar, J. J. (2020). Bilingual pre-service teachers and their opportunities to learn. *Investigations in Mathematics Learning*, *12*(4), 289-303. https://doi.org/10.1080/19477503.2020.1836458

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press. https://doi.org/10.1017/CBO9780511815355

Lesh, R., & Doerr, H. M. (2003). *Beyond constructivism, models and modeling perspectives on mathematics problem solving, learning, and teaching*. Lawrence Erlbaum Associates. https://doi.org/10.4324/9781410607713

Martín-Gutiérrez, J., Mora, C. E., Añorbe-Díaz, B., & González-Marrero, A. (2017). Virtual technologies trends in education. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(2), 469-486. https://doi.org/10.12973/eurasia.2017.00626a

Mayer, B. W., Dale, K. M., Fraccastoro, K. A., & Moss, G. (2011). Improving transfer of learning: Relationship to methods of using business simulation. *Simulation & Gaming*, *42*(1), 64-84. https://doi.org/10.1177/1046878110376795

Miles, M. B., Huberman, A. M., & Saldaña, J. (2018). *Qualitative data analysis: A methods sourcebook*. SAGE.

Mills, J., & Birks, M. (2014). *Qualitative methodology: A practical guide*. SAGE. https://doi.org/10.4135/9781473920163

Moyer, P. S., & Milewicz, E. (2002). Learning to question: Categories of questioning used by preservice teachers during diagnostic mathematics interviews. *Journal of Mathematics Teacher Education*, *5*(4), 293-315. https://doi.org/10.1023/A:1021251912775

Murphy, K. M., Cook, A. L., & Fallon, L. M. (2021). Mixed reality simulations for social-emotional learning. *Phi Delta Kappan*, *102*(6), 30-37. https://doi.org/10.1177/0031721721998152

Mursion. (2016). *About us*. http://www.mursion.com

NCTM. (2014). Principles to actions: Ensuring mathematical success for all. *National Council of Teachers of Mathematics*. https://www.nctm.org/Store/Products/Principles-to-Actions--Ensuring-Mathematical-Success-for-All/

O'Connor, C., & Joffe, H. (2020). Intercoder reliability in qualitative research: Debates and practical guidelines. *International Journal of Qualitative Methods*, *19*, 1609406919899220.

Perkins, D. N., & Salomon, G. (1992). Transfer of learning. *International Encyclopedia of Education*, *2*, 6452-6457.

Pomerance, L., & Walsh, K. (2020). 2020 teacher prep review: Clinical practice and classroom management. *National Council on Teacher Quality*. www.nctq.org/publications/2020-Teacher-Prep-

Review:-Clinical-Practice-and-Classroom-Management

Qi, Y., & Sykes, G. (2016). Eliciting student thinking: Definition, research support, and measurement of the" ETS"® national observational teaching examination (NOTE) assessment series. Research memorandum No. RM-16-06. *Educational Testing Service*.

Saldaña, J. (2021). *The coding manual for qualitative researchers*. SAGE.

Sander, S. A. (2014). *Exploring preservice science teachers' interpretations of curricular experiences while learning to teach in an inquiry-oriented way: A phenomenology* [Doctoral dissertation, Miami University].

Shahrill, M., & Mundia, L. (2014). The use of low-order and higher-order questions in mathematics teaching: Video analyses case study. *Journal of Studies in Education*, *4*(2), 15-34. https://doi.org/10.5296/jse.v4i2.5318

Starcher, K. (2011). Intentionally building rapport with students. *College Teaching*, *59*(4), 162-162. https://doi.org/10.1080/87567555.2010.516782

Stein, M. K., Engle, R. A., Smith, M. S., & Hughes, E. K. (2015). Orchestrating productive mathematical discussion: Helping teachers learn to better incorporate student thinking. In L. B. Resnick, C. S. C. Asterhan, & S. N. Clarke (Eds.), *Socializing intelligence through academic talk and dialogue* (pp. 357-388). https://doi.org/10.3102/978-0-935302-43-1_29

Stuhlman, M. W., Hamre, B. K., Downer, J. T., & Pianta, R. C. (2009). How classroom observations can support systematic improvement in teacher effectiveness. *University of Virginia Curry School of Education*, *3-4*. https://education.virginia.edu/sites/default/files/uploads/resourceLibrary/CASTL_practioner_Part5_single.pdf

TeachingWorks. (2016). *High-leverage practices*. http://www.teachingworks.org/work-of-teaching/high-leverage-practices

Tinsley, H. E. A., & Weiss, D. J. (2000). Interrater reliability and agreement. In H. E. A. Tinsley, & S. D. Brown (Eds.), *Handbook of applied multivariate statistics and mathematical modeling* (pp. 95-124). Academic Press. https://doi.org/10.1016/B978-012691360-6/50005-7

Van Blankenstein, F. M., Dolmans, D. H., van der Vleuten, C. P., & Schmidt, H. G. (2011). Which cognitive processes support learning during small-group discussion? The role of providing explanations and listening to others. *Instructional Science*, *39*(2), 189-204. https://doi.org/10.1007/s11251-009-9124-7

Ward, P., Chen, Y. J., Higginson, K., & Xie, X. (2018). Teaching rehearsals and repeated teaching: Practice-based physical education teacher education pedagogies. *Journal of Physical Education, Recreation & Dance*, *89*(6), 20-25. https://doi.org/10.1080/07303084.2018.1476937

Wilkinson, L. C., & Martino, A. M. (1993). Students' disagreements during small-group mathematical problem solving. In R. B. Davis, & C. A. Maher (Eds.), *Schools, mathematics and the world of reality* (pp. 135-171). Allyn and Bacon.

Wimer, J. W., Ridenour, C. S., Thomas, K., & Place, A. W. (2001). Higher order teacher questioning of boys and girls in elementary mathematics classrooms. *The Journal of Educational Research*, *95*(2), 84-92. https://doi.org/10.1080/00220670109596576

Zhou, Z. (2011). The clinical interview in mathematics assessment and intervention: The case of fractions. In M. A. Bray, & T. J. Kehle (Eds.), *Oxford library of psychology. The Oxford handbook of school psychology* (pp. 351-366). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195369809.013.0131