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An Examination of Practice-Based Virtual Simulations and Pre-Service Mathematics Teaching Efficacy and Outcome Expectancy

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Abstract: Authentic practice in pedagogical approaches is essential for preparing teachers to design effective learning experiences that foster student engagement during this digital era. There is an opportunity to explore novel and effective designs of virtual experiences that may augment or better prepare preservice teachers for field placements in physical classrooms. We proffer that virtual classroom simulations can and should be further explored and leveraged, now more than ever. In this paper, we examined a model of the impact of perceptual variables on instructional effectiveness that can enhance teaching efficacy and outcome expectancy when preservice teachers engage in practice teaching experiences in a virtual classroom simulation. The relationships between perceptual variables (presence, instructional time, and engagement) and teaching efficacy and outcome expectancy, as they relate to instructional effectiveness, were analyzed using the structural equation modeling approach. The results supported all of the hypothesized relationships. For example, presence and instructional time strongly and positively influenced engagement. Engagement was strongly related to instructional effectiveness. Instructional effectiveness was strongly and positively related to teaching self-efficacy, as well as outcome expectancy. The results support that virtual world classroom simulations can be an effective space for practice teaching for prospective mathematics teachers. Furthermore, this study provides insights for teacher educators, developers, and instructional designers interested in designing and utilizing practice-based simulations.

Keywords: simulations; Second Life; virtual world; preservice; practice-based teaching; mathematics teaching efficacy; teacher education

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Citation: Davis, T.J.; Merchant, Z.; Kwok, O.-M. An Examination of Practice-Based Virtual Simulations and Pre-Service Mathematics Teaching Efficacy and Outcome Expectancy. *Educ. Sci.* **2022**, *12*, 262. https://doi.org/10.3390/educsci12040262

Academic Editors: Juanjo Mena and Elvira G. Rincón Flores

Received: 11 November 2021
Accepted: 1 April 2022
Published: 7 April 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Authentic practice in pedagogical approaches is essential for preparing teachers to design and engage students in effective learning experiences in mathematics as well as other disciplines. Clinical teaching experiences and alternative clinical experiences have been well-documented as a fundamental component of teacher preparation programs [1,2]. Moreover, teacher educators are keenly aware of the disciplinary knowledge, skills, and mindsets required for candidate success, and therefore continue to explore inventive ways to design learning experiences to better prepare prospective teachers. For several years, teacher educators have explored practice-based settings, and these designs deviate widely in their effectiveness [and approach] [3] (p. 484). They have been challenged with finding the right design and time allocation balance or "sweet" spot between engaging preservice teachers (PSTs) in instructional design versus an overemphasis in classroom management and discipline. As Girod and Girod [3] explicate, preservice teachers may be more eager to explore the latter (p. 483).

In recent years, researchers have explored the potential of utilizing virtual simulations in various teaching and learning contexts [4–6]. In the project described here, we explored Second Life® (SL) for its effectiveness in providing a platform for our design and use of a simulated middle grade classroom to develop teacher knowledge through practice-based experiences. We used several strategies in a mathematics problem solving course. We believed virtual simulations could provide preservice teachers with practice and experience in designing, presenting, and critiquing their problem-solving lessons (and those of their peers) to develop effective and equitable approaches in their teaching. When designed well, these unique virtual spaces can provide a safe setting for PSTs to practice their craft [7,8]. The immersion in teaching their lessons to a classroom of middle grade students (in this case avatars) provided a safe space and forced a reckoning of sorts with the timing, tensions, choreography, and organic nature of classroom engagement that occur as one teaches. We posited that the degree to which PSTs felt present in the space and had time to immerse themselves in successful practice teaching simulations could result in positive outcomes (e.g., meaningful engagement with students in the virtual classroom, teaching efficacy). In related work, preservice teachers reported the benefit of having early practice with avatars in the simulated classroom before engagement with real students, and that made them feel better prepared [9,10]. In the current study we examined more closely the relationships between instructional effectiveness, engagement, and other key variables (presence and instructional time), and their subsequent effect on personal mathematics teaching efficacy and outcome expectancy. These relationships were examined in the context of a practice-based setting, with the central actors (i.e., preservice teachers) engaged in virtual classroom simulations.

2. Background

2.1. Simulations in Teacher Education

Past research suggests that typical field experiences may not always result in the intended outcomes (e.g., [1,2]). Teacher educators have long explored inventive methods for practice-based experiences for preservice teachers [1]. Importantly, Grossman et al. [11] offer a useful framework for teaching practice that describes the engagement of novices in activities of representation, decomposition, and approximation (p. 2064). For example, within representations of practice, "novices can observe how practices are carried out" (e.g., direct observation, videos explicating techniques, role-play). The authors elaborate, "although decomposition is useful in developing professional vision-decomposing practice also allows [novice teachers] to begin to enact practice, to practice a relatively narrow skill in a safe space" (p. 2072). Similarly, "opportunities for enactment and experimentation occur through the use of approximations of practice. Students may be asked to simulate certain aspects of practice through activities such as role-play" (p. 2076).

Moreover, teacher educators have explored evolving approaches to engage preservice teachers in effective classroom practices that have included the use of virtual classroom simulations in various forms [12–14]. Bradley and Kendall [15], in their review of computer simulations in teacher education, outlined a number of simulations available to teacher educators and described them by the categories of "virtual puppetry simulations, multi-user virtual environments (MUVEs), and single user simulations" (p. 7). Their descriptions follow, and illustrative platform examples have been inserted [15,16]:

- Virtual puppetry simulations [including mixed reality] are synchronous. Preservice teachers engage with actors in the virtual environment (i.e., students in class) [e.g., Teacher Talk Game, TLE TeachLivETM, Mursion, SimLab™ powered by Mursion].
- Multi-user virtual environments allow multiple users (students) to interact synchronously in the environment [e.g., OpenSim, Active World, Second Life, TeacherSim powered by OpenSim].
- Single-user simulations have "pre-programmed responses to complex threads of interactions between the preservice teacher and the simulated student" [e.g., simSchool,

Classroom Sim, At risk for High School Educators, At risk for Middle School Educators, Step In Speak Up!, Cook School District Simulation (p. 7)].

Much has been learned from the body of scholarship in teacher education centered in the utilization of simulation platforms. The potential of simulation platforms to facilitate an array of skills, knowledge, understandings, and approaches that are of import for preservice teachers is well highlighted in the literature [17] (p. 1). The unique features of simulation platforms and their affordances, benefits, and efficacy of deployment, as well as their limitations in teacher preparation contexts, have also been well documented [3,18,19]. Christensen, Knezek, Tyler-Wood, and Gibson [18], for example, described in a paper on simSchool the various features and benefits of using the platform, e.g., it provided a safe space for practicing techniques, especially approaches that addressed learning styles (p. 27). Simulations have also been shown to provide safe-to-fail environments [13,20] in which preservice teachers have the freedom to practice, take risks, and engage in productive failure. In some instances, preservice teachers are afforded the opportunity and time for repeated, reflective practice [17]. In an early paper on *Teacher Education with simSchool*, Gibson [18] described the potential benefits of simulations thusly:

> One benefit is *shearing away details in a simplification of a real system*. Models allow us to hold, in our hands and minds, some aspects of a system that cannot otherwise be experienced. Connected to and entailed by the characteristic of simplification is *increased safety* (e.g., a pilot in training can crash a virtual plane and a beginning teacher can crash a student or a class) . . . and *enhanced focus on the relationships* among the simplified features (e.g., making a theory operational and amenable to manipulation). Simulations also provide *multiple chances to practice*, including making attempts with higher risks and causing spectacular failures, and to learn, retry and master new skills . . .

Moreover, Dalinger, Thomas, Stansberry, and Xiu [21] investigated how teacher candidates perceived the effects of the mixed reality simulation (Mursion) on their (a) confidence, (b) live classroom/parent experiences, and (c) as tools for targeted skills practice. They found that four main themes emerged: opportunity for authentic practice, perceived transfer of learning, perceived confidence, and challenges of using the simulation. Dalinger et al. found, for example, that participants perceived the simulation as providing authentic practice via the spontaneous nature of an actual classroom (p. 8). Ledger et al. [17], in their literature review, also claim that, "[d]espite research indicating the potential of simulation platforms, research consistently highlights the challenges and complexities associated with effective integration of simulation in teacher education, and its uptake has been considered inconsistent and sporadic" (p. 2). Next, we discuss the research on simulations, predominantly within a Second Life and teacher education context.

2.2. Second Life and Teacher Education

One of the most notable and widely used examples of a MUVE is the virtual world of Second Life® [22]. Kuznetcova and Glassman [22] summarize the evolution of Second Life and note that it gained a great deal of interest after its inception nineteen years ago. They recounted that interest in educational applications of SL surged during the first ten years of its existence but began to decline a bit after that (p. 390). Kuznetcova and Glassman aptly note that newer technologies emerged, like immersive virtual reality (VR) headsets, alongside the rapid development of augmented reality (AR) and advanced designs in the game industry. They also observe that other MUVEs did not "quite strike the balance of financial and hardware accessibility, the open-ended exploratory nature of the environment, and multiple aspects and channels of communication in the same way SL does" (p. 390).

The Second Life platform has also been used in an array of projects [albeit sporadic] focused on engaging preservice teachers or undergraduate students in various teaching or learning activities. Engagement in Second Life has spanned multiple teacher preparation foci, including classroom management [20,23], language learning [24], special education [25,26], science [27], mathematics [28], educational technology [29], and parent-teacher engagement [20]. The utilization of Second Life (or simulations in general) in teacher education has been examined in empirical studies and summarized in literature reviews, and the benefits and limitations of, or barriers and enablers to, using Second Life in teacher education, have also been well documented (e.g., [17,30]). Ledger et al. [17], in their 2021 literature review, explored the complexity of utilizing simulation platforms (Second Life in particular) in initial teacher education (ITE). Ledger and colleagues examined the trends in the literature on the benefits and limitations of Second Life in ITE (p. 3). Select findings are highlighted below [17].

1. The range and depth of practicum experiences can be broadened when delivered in virtual worlds. Preservice teachers can engage with a range of students (avatars) exhibiting various educational challenges (p. 7).
2. Among the benefits cited, the potential of simulation platforms to provide collaborative, reflective, and skill development opportunities of engagement for preservice teachers was the most common (p. 7).
3. The utilization of Second Life (or similar platforms) by initial teacher educators offers opportunities and challenges in facilitating a learning environment that can assist preservice teachers in developing pedagogies of practice via representations, decomposition, and approximations of practice (from the Grossman et al. [11] framework) (p. 9).

In addition, Puvirajah and Calandra [20] analyzed the experiences of a novice teacher enrolled in an alternative teacher preparation program participating in role-play in a collaborative virtual world parent-teacher conference. They explicated that "well-designed experiences in collaborative virtual worlds [like Second Life] coupled with meaningful reflections of those experiences have the potential to allow novice teachers to feel and act like a teacher" (p. 43). Puvirajah and Calandra referred to this phenomenon as *embodiment* and also described that "embodiment can be thought of as the sense of presence felt by collaborative virtual world participants" (p. 26). The authors stated that appropriately designed experiences in virtual worlds can provide practice in skills associated with a particular profession. They offered that the "situated nature of collaborative virtual world experience can play an important role in developing professional identity" (p. 26). As preservice teachers are engaged, the learning is not just about how to do things; they can also start down a path of *learning to be* (p. 26).

The current study is situated within a practice-based mathematics teacher education context [31]. Practice-based mathematics teacher education has predominantly taken place in face-to-face environments [31] but has been expanded to virtual environments in recent years. Herbst et al. [31] highlight this point and extend the Grossman et al. [11] framework for teaching practice for consideration in thinking about technology–mediated practice teaching environments (p. 80–84). They maintain that "the work of teaching, while requiring substantial explicit knowledge (e.g., factual and conceptual mathematics knowledge), also requires important tacit knowledge" (p. 79). In addition, novel approaches in teacher education have advanced to include the use of virtual worlds to provide practice-based teaching simulations. Simulations can be designed to immerse mathematics preservice teachers in settings that provide focused practice with learners (in this case avatars). The avatars can be programmed with diverse backgrounds, and they can elicit targeted mathematics misconceptions and learning needs that may not always be readily observed in on-campus or more typical field experiences [4,32]. There are a variety of examples of the use of virtual worlds or virtual simulations in learning contexts (e.g., [33–39]). However, there are few instances of mathematics classroom simulations that focus primarily on the delivery of problem-solving or mathematics lessons in Second Life [4,9,10], as is investigated in the current study.

2.3. Perceptual Variables

Engagement and Instructional Effectiveness. Engagement and instructional effectiveness are two of the variables of interest in the current inquiry. Several investigators have ideas about how 3-D virtual environments can facilitate learning (e.g., [33,35,39]).

Salzman et al. underscore that the features of virtual learning environments do not act in isolation. Rather, important factors like the "concepts or skills to be learned, individual characteristics, the learning experience, and the interaction experience, all play a very important role in shaping the overall learning process, along with the various learning outcomes" (p. 293). Cheng [40], in his work with undergraduate students in a digital imaging course, examined students' learning styles in relation to their acceptance of using Second Life. Cheng found that active learners valued the ease of use and usefulness of Second Life for engaging with course content, while verbal learners valued its communication and identity features. Further, the results offered instructional implications for using Second Life. For example, instructors should provide opportunities for students to learn in an active way; "[instructors can] also design learning activities like role-play, presentation or group discussion through avatars in SL to encourage student's self-expression and increase the course [engagement]" (p. 113).

There have been mixed findings related to instructional effectiveness in Second Life contexts. Burgess [29] posited that as learners participate in SL, engagement is enhanced through immersive experiences which result in optimal learning. As participants engaged in reading activities in SL, Burgess found that enjoyment was an important factor "that served as a springboard for other optimal experience components" (p. 126). Similar findings are reported related to the effect of other perceptual constructs on science learning in SL (e.g., [13]).

Mirliss, May, and Zedeck [41] found that preservice teachers that served in both teacher or audience (student) roles reported benefitting from engaging in classroom simulations in Second Life. An analysis of presence data showed significant differences with the teacher group related to engagement, and a sense of physical space. The simulation actors (i.e., teachers) "felt more psychologically involved and enjoyed the content, had higher perceptions of the environment as being lifelike and real, and had a greater sense of being there" (p. 156). Wrzesien and Raya [42] found that learning effectiveness when students participated in a MUVE was not increased with younger students, but the participants conveyed better engagement and enjoyment. In addition, Cheong [43] found that teacher practice in SL had mixed results. It appeared that skill outcomes did not exceed those from regular classroom settings, but the benefit of engaging in MUVEs came from collaborative experiences.

Papachristos, Vrellis, Natsis, and Mikropoulos [44], in their work with preservice teachers using Second Life, investigated the effect of the design of the educational setting on learning outcomes, experience, attitudes, and social presence. Among the results, they found that the PSTs' experiences and attitudes toward the MUVE were positive and were not affected by the design of the educational setting. It was also found that the presence dimensions were moderately to strongly correlated with easiness for active participation, among other variables. It was also shown by Dalgarmo, Gregory, Knox, and Reiner [13] that preservice teachers that engaged in role-play activities in the VirtualPREX classroom environment in SL found that practicing in the role of the teacher was efficacious in several ways. It was helpful in preparing preservice teachers' for professional placement and valuable in developing their ability to respond to unexpected classroom events *as a teacher*, structure a lesson, provide clear instructions to students, and manage realistic student behaviors (p. 144). We note that the importance of actively engaging as a teacher in the context of delivering a lesson in a classroom simulation is worth underscoring.

As the aforementioned work illustrates, instructional effectiveness and engagement can be operationalized in a variety of ways, typically drawing from the contexts of the particular studies. In the current study, engagement refers to preservice teachers' perceptions about the experience of engaging in exercises and giving lessons in Second Life. Specifically, participants were asked to indicate if their practice teaching sessions allowed them to engage with middle grade student (MGS) avatars in a meaningful way. Likewise, we operationally define instructional effectiveness as preservice teachers' perceptions of the overall effectiveness of the tutoring and teaching sessions they led in SL.

Presence. Presence is another construct of interest in the current model. Witmer and Singer [45] argued that 3-D virtual environments have a significant advantage over 2-D environments in that they induce a higher sense of presence. Presence can be loosely defined by the perception that, as avatars, participants are able to feel as if they are in the same room or space as others (e.g., their students or classmates). This has been reported across multiple studies [45–47]. Davis, Phillips and Kulm [4] discussed findings from Mikropoulos and Natsis [47] and reported that presence as a perceptual construct has been referenced in multiple studies "as a key to improving involvement [or engagement] and by implication, outcomes" (p. 188).

Presence has also been described by some as a human reaction to immersion [48]. Lee et al. [48] recounted that participants can experience greater presence when they engage in more immersive MUVEs (p. 1428). Dede, Jacobson, and Richards [49] elucidated that MUVE interfaces offer participants an engaging experience in a simulated setting in which their digital avatars convey immersion in a graphical, virtual context, and the participant feels a remote presence inside the virtual environment (p. 4). They explained that "powerful immersion for learning depends on designs that utilize actional, social, and symbolic/narrative factors" (p. 4). In discussing social immersion, Dede and contributors further offered that "rich social interactions among participants in a shared virtual or mixed reality deepens their sense of immersion." Comparable to the real world, to the extent that virtual environments can support "shared processes of reasoning between people who leverage their environment", a user can be drawn into the virtual environment and feel more a part of it (p. 5).

In addition, Chen, Warden, Tai, Chen, and Chao [50] reported that immersion is often better when interface or technological improvements are made. Increased authenticity and representational fidelity [48] can also positively impact participants' sense of presence. Chen et al. also explored how environment abstraction levels influenced students' sense of presence, and found that high abstract environments reduced presence, while low abstraction increased presence.

Notably, Mikropoulos, and Natsis [47], in their review of research on the educational applications of virtual environments, reported that, in over a third of the reviewed studies, authors reported that participants in their samples had a feeling of *being there*. In three of the studies, they reported that presence contributed to positive learning outcomes. Specifically, students experienced a profound sense of presence interacting in virtual environments, and it was noted that that factor aided them in accomplishing their learning tasks more successfully. More recently, Schultze and Brooks [51] developed a more contemporary, interactional view of social presence. They considered social presence as contingent on social practice, and they explored how social presence is achieved in MUVEs like SL. An outcome of their work was the development of an interactional model of social presence.

Ke, Lee, and Xu [52] summarized the prior research on presence thusly: the "sense of presence reduces the social distance between learners and enhances skills acquisition and knowledge transfer by allowing multiple perspectives and situation performance" (p. 213). They add that the sense of presence in virtual learning environments fosters "learning engagement, and potentially learning outcomes, by enabling focused and naturalistic interactions with learning materials and activities" (p. 213). In addition, McClannon, Cheney, Bolt, and Terry [53] conducted research between 2010 and 2017 involving over a thousand education graduate students engaged in immersive MUVEs in their courses. In their examination, they predicted students' perceptions of presence and community using student engagement factors and course structure factors. Among the results, they found that the benefits of the environment on the students' sense of presence was maximized by the students' time per week in the environment. Moreover, the sense of presence was enhanced for students that were required or encouraged to spend more time in the environment.

Instructional Time. The next variable of interest, instructional time, can be an important consideration in technology acceptance and use research. In the context of a computer-mediated learning environment, we can operationalize instructional time in two ways:

(1) the amount of time one is using the technology [54] or, in this case, the time that the participants engage in the MUVE, or (2) the frequency in which they engage. Dede et al. [49] proffer:

> [T]o maximize the power of immersive learning it's important not to present isolated moments in which VR, MUVEs and AR are used to provide short-term engagement or fragmentary insight. Instead, extended experiences that immerse students in rich contexts … with authentic practices, and links to real world outcomes are what truly unleash the transformative power of immersion. (p. 7)

Quintana and Fernández [8], in their work with students in initial teacher training, presented a pedagogical model for teaching in virtual worlds, i.e., Second Life. The model entailed building scenarios that engaged preservice teachers in decision-making and building meaningful learning experiences (p. 596). The underlying premise was "the greater number of simulations performed, the greater expertise in developing training solutions will be acquired" (p. 596). Furthermore, Cheng [41] found that students reported insufficient teaching and learning time as a practical issue during their course. He discussed a possible tension in teaching between the time required to learn the course content and SL technology. In a practical sense, Cheng's finding suggests that more time should be allocated to courses that integrate Second Life (p. 113).

In contrast to the Christensen, Knezek, Tyler-Wood, and Gibson's [18] design of engaging preservice teachers in extended time (i.e., seven 90-min sessions), Rayner and Fluck [12] investigated the effectiveness of using a simulation (SimSchool) over a briefer period of time (i.e., two-hour sessions). They found that preservice teachers in an inclusive education course felt the "time spent using simSchool was equivalent to half the same time spent observing a real classroom, and equivalent to a quarter of the time spent teaching in a real classroom for their development as educators" (p. 219). Rayner and Fluck noted that this implied that some preservice teachers deemed the simulation highly acceptable while for others it was dissimilar to a real classroom situation (p. 219).

More analogous to the current study, the first author and colleagues found in their earlier work that preservice teachers conveyed they would benefit from additional Second Life® teaching experiences. The PSTs expressed that more time in the environment prior to delivering their problem-solving lessons later in SL would be beneficial [10,32]. These adjustments were made in the problem-solving courses. In a related investigation of preservice teachers' perceptions of working with middle grade student avatars in SL, it was reported that participants predominantly felt they were allotted adequate time for each of the exercises. However, in some instances preservice teachers indicated more time was needed [10]. Additionally, preservice teachers expressed that meeting the middle grade student avatars early in the semester was helpful. This gave them an opportunity to learn about their backgrounds and interests, and the mathematics concepts they were struggling with. Preservice teachers also expressed that opportunities to engage with MGS avatars and practice in the virtual classroom before they taught their final problem-solving lessons were a valuable preparation [55].

Self-Efficacy and Outcome Expectancy. In Bandura's [56] preeminent work, self-efficacy is described as consisting of both outcome expectancy and self-efficacy. Outcome expectancy is defined as one's belief that a specific behavior will generate particular outcomes [56]. He described an efficacy expectation as the belief that one can successfully perform the task needed to generate the desired outcome. Bandura makes this distinction because, as he points out, one can believe that a particular behavior will yield the desired results, but if individuals are not confident in their ability to achieve the needed actions, such information will ultimately not impact their performance. This foundational work has relevance for the current study.

Several researchers have investigated self-efficacy and outcome expectancy as it relates to teaching (e.g., [57–60]). Enochs et al. [59] summarized these constructs as "personal teaching efficacy has been defined as a belief in one's ability to teach effectively and teaching outcome expectancy as the belief that effective teaching will have a positive effect on student learning" (p. 195). Sitzmann [61], in her work, summarized that self-efficacy was higher in studies where participants were taught through simulation games. She recounted that an essential antecedent to high self-efficacy is gaining experience with key tasks (p. 495).

This notion of the importance of engagement in work-related tasks is illustrated in Huinker and Madison's [62] investigation. They studied the impact of the experiences of preservice elementary mathematics and science teachers. They employed a pretest-posttest design and found significant increases for both the mathematics and science PSTs on both the efficacy and outcome expectancy subscales.

Cheong's [43] work with preservice teachers resulted in mixed findings. He investigated the effect of practice teaching in SL on changes in PSTs' teaching efficacy. Preservice teachers were enrolled in a teaching methods and educational technology course. Notably, he found that PSTs' practice teaching brought about changes in their personal teaching efficacy but not in their outcome expectancy. Cheong also found that collaborative practice teaching was a more effective approach to practice teaching than individual approaches. Additionally, Celik and Yesilyurt [63], in their work with preservice teachers, found that their attitude about technology, perceived computer self-efficacy, and computer anxiety were significant predictors of PSTs' beliefs toward using computer-supported education.

Christensen, Knezek, Tyler-Wood, and Gibson [18], in their study with preservice teachers, found that after engaging in simSchool-centered activities for seven 90-min sessions, the treatment class produced significant gains in instructional self-efficacy (twice as much) as the comparison group that engaged in face-to-face interaction. Both groups had comparable class time exposure (p. 25). They also reported significant gains in preservice teachers' instructional self-efficacy with students with disabilities [12,18].

In their work with preservice early childhood teachers, Bautista and Boone [64] investigated the impact of practice experiences in a mixed reality environment, TeachME^{TM} Lab (TML), on preservice teachers' science teaching self-efficacy beliefs. They found that factors such as their familiarity with the TML virtual environment, peer observations, and the act of teaching avatars provided sources of efficacy" and thus increased self-efficacy was reported by the PSTs (p. 254).

We return to the work that Lee et al. [48] conducted in their SEM analysis of the effect of virtual reality on learning outcomes. Lee et al. posited that VR features have an indirect effect on learning outcomes, which are mediated by both the interaction experience and the learning experience (the experience of the learner as being physically located in the mediated space). Lee et al., in making sense of their findings, suggested that the positive relationship between VR features and presence indicated that the better the VR features in terms of realism and user control, the higher the experience of presence. Finally, we offer that providing preservice teachers' practice teaching experiences in a classroom environment in a virtual world can help to develop their pedagogical skills when teaching algebra.

2.4. Testing the Model

Within the context of our project, we sought to investigate preservice mathematics teachers' perceptions of presence, instructional time, and engagement, along with instructional effectiveness, mathematics teaching efficacy, and outcome expectancy, as they participate in classroom teaching simulation exercises throughout a semester-long problem-solving course.

We developed and tested a latent factor mediation model of preservice teachers' experiences and learning processes in a classroom in Second Life to develop their pedagogical skills when teaching algebra for equity. We conducted a structural equation modeling analysis. The model consisted of four latent factors: instructional time, instructional effectiveness, mathematics teaching efficacy and outcome expectancy, and two observed variables of presence and engagement. We tested the following nine hypotheses to assess the fit of the hypothesized model.

Hypotheses for testing direct relationships.

Hypothesis H1. *Instructional time is positively and significantly related to engagement.*

Hypothesis H2. *Presence is positively and significantly related to engagement.*

Hypothesis H3. *Engagement is positively and significantly related to instructional effectiveness.*

Hypothesis H4. *Instructional effectiveness is positively and significantly related to teaching self-efficacy.*

Hypothesis H5. *Instructional effectiveness is positively and significantly related to students' outcome expectancy.*

Hypotheses for testing indirect relationships.

Hypothesis H_{01}. *Engagement will mediate the relationship between instructional time and instructional effectiveness.*

Hypothesis H_{02}. *Engagement will mediate the relationship between presence and instructional effectiveness.*

Hypothesis H_{03}. *Instructional effectiveness will mediate the relationship between engagement and teaching self-efficacy.*

Hypothesis H_{04}. *Instructional effectiveness will mediate the relationship between engagement and students' outcome expectancy.*

3. Method

The data for this study were part of a series of investigations that were conducted for our National Science Foundation (NSF)-funded project. We focus in the current study on aspects of activities completed by PSTs to practice their algebra-teaching skills in a virtual classroom in SL.

3.1. Participants

The 59 participants were mathematics preservice teachers enrolled in either the spring or fall semester's required mathematics problem-solving course at a large southwestern university with a very high research activity. The upper-division undergraduate classes consisted of 40 juniors and 16 seniors. There were 48 White females, 1 African American female, 9 Hispanic females, and 6 White males. These demographics reflect the overall population of preservice teachers at the university.

3.2. Measures

We used two self-report measures to collect data for this study. These self-report measures were the Mathematics Teaching Efficacy Behavior Instrument (MTEBI) and the Preservice Teacher Second Life Engagement (PTSLE) Instrument. The MTEBI consists of 21 items, including 13 items on the personal mathematics teaching efficacy subscale and eight items on the mathematics teaching outcome expectancy subscale developed by Enochs et al. [35]. Items for the MTEBI were based on a five-point Likert scale ranging from strongly disagree to strongly agree. Enochs et al. report reliability alpha coefficients of 0.88 and 0.75 for the two subscales. The PTSLE is a nine-item instrument consisting of four variables developed by the first author. The four variables were instructional time (4 items), presence (1 item), engagement (1 item), and instructional effectiveness (3 items). Items for the PTSLE measure were based on a ten-point scale ranging from strongly disagree

(0) to strongly agree (10). For reliability coefficients of the variables included in the study, please refer to Table 1.

Table 1. Descriptive statistics for variables included in the models.

	1	2	3	4	5	6
Mean	25.54	5.88	6.68	20.69	40.54	27.47
SD	7.35	2.84	2.28	5.46	4.00	3.06
Inter-correlation coefficients						
1	1.00					
2	0.47 **	1.00				
3	0.62 **	0.76 **	1.00			
4	0.81 **	0.61 **	0.79 **	1.00		
5	0.38 *	0.29 *	0.41 **	0.45 **	1.00	
6	0.32 *	0.25	0.26	0.28 **	0.35 **	1.00

1 = Instructional Time; 2 = Presence; 3 = Engagement; 4 = Instructional Effectiveness; 5 = Self-Efficacy; 6 = Outcome Expectancy. * Coefficient is significant at the 0.05 level (2-tailed). ** Coefficient is significant at the 0.01 level (2-tailed).

3.3. Procedure

3.3.1. Virtual Middle School Classroom

Following our past success with other virtual world projects, Second Life®, developed by Linden Labs, also provided an ideal platform for our work reported here [65]. The first author, along with a seasoned SL development team, designed a virtual middle school classroom and interactive spaces in Second Life to support our project work. Second Life allows for participants using the Second Life or compatible clients to view and interact with the simulated virtual environment using a personal computer. The user manipulates a typically human-like representation or avatar in order to move around and interact with the virtual world. Our project virtual classroom simulation is a 3-D modeled space where a classroom full of simulated students (avatars) are controlled and used to interact with preservice teachers. Standard PC technology (keyboard, mouse, headset, and monitor) is used as the hardware interface into the virtual world. Our SL classroom environment was created to give the feeling and appearance that the users are walking around in a real classroom and interacting with a medium-sized class composed of 15 individualized middle grade students (i.e., bot avatars or robot non-player characters), each designed with specific appearances, backgrounds, and interests. Generally, an avatar is a simulated character controlled by a human, and a bot is a non-player character controlled by programming and scripting [23]. The simulated students in our classroom can raise their hands, perform a series of gestures to demonstrate their current level of understanding, or speak any of a series of lines that have been prerecorded by live voice actors, specifically for each individual simulated student. Through using the HUD (heads-up display) interface, a single user or small group of users can simulate the actions and responses of a full classroom of students, described as virtual or digital puppetry by Bradley and Kendall [15] and Bautista and Boone [65]. In addition, five to six *live* avatars of middle grade students are also role-played by graduate and undergraduate student members of the research team. During the beginning of the problem-solving course, preservice teachers set up their teacher avatar and completed an immersive eight-station orientation on engaging in Second Life and using our virtual spaces. Multiple investigators suggest that learners should be given sufficient time for training and support to be able to successfully engage in Second Life [40,44].

Throughout the problem-solving course, PSTs participated in several practice-based tutoring and teaching activities in SL. The virtual classroom was designed to foster engagement between the preservice teachers and the middle grade student avatars and included different resources and tools (e.g., display screens for various media, interactive white board) and a gesture menu (Figure 1). The gesture menu included a hand-raising gesture and questioning/confirmation gestures (i.e., red question mark [indicated "I don't get it, I'm lost"], yellow question mark [indicated "I think I see what you mean, I'm almost with you"], green light bulb [indicated "I get it"]). These visual pop-up cues were added later to the virtual classroom design to further support lesson engagement.

Figure 1. Virtual classroom and gesture menu.

3.3.2. Second Life Teaching Exercises

Preservice teachers engaged in various Second Life® simulation and training sessions in the course: (a) Meet Your Middle Grade Students, (b) Tutoring Middle Grade Students, and (c) Problem Solving Lesson Teaching Experience [10,66]. Meet your middle grade students was an introductory exercise where preservice teachers met live avatars of middle grade students, a role played by graduate students. In preparation, PSTs reviewed the MGS's school records. During the meeting they learned more about their interests, background, and math experiences and used this information and experience to help plan their tutoring session. These initial sessions also helped PSTs gain familiarity with the virtual classroom features and interactive tools (Figure 2).

Figure 2. Middle school classroom during the "meet your student" exercise.

Tutoring the middle grade students was a brief tutoring exercise. PSTs met with MGSs one-on-one to work on a mathematics problem they needed help with. The problem was shared with the PST early so they could work on an approach that would be the most effective. The MGS avatar's role-playing included predetermined math misconceptions that the PST needed to address during the tutoring session.

Problem-solving lesson teaching experience: During the final four weeks of the course, PSTs prepared algebra lessons to teach the MGS avatars in the virtual classroom. The PSTs went to a separate room during the teaching sessions and logged into SL as an avatar (teacher). The problem-solving lessons typically included PSTs giving their lessons while they projected their slides on a large display screen in the SL classroom. Throughout the lesson, they talked with MGSs and used an interactive pen display (i.e., SmartPodium tablet) to model and work out math problems (also projected on a screen in real time). Throughout the lesson, PSTs responded to any questions or misconceptions MGSs had (Figure 3). Opportunities to observe peers, critique their lesson designs, and later discuss and debrief on their teaching approaches in the SL classroom, were also an important element of the instructional design of the course.

Figure 3. Problem-solving lesson in virtual middle school classroom.

4. Results

A structural equation modeling (SEM) approach was used for this study. For all the variables included in the model we report descriptive statistics in Table 1. Based on Cohen's (1988) guideline, all the statistically significant correlation coefficients presented in Table 1 were at least close to the medium effect size (0.30), and many of them were above the large effect size (0.50) as recommended by Cohen [67]. SEM is a commonly used analytic approach, given that (1) measurement errors and the corresponding error variances can be separated from using a latent factor model or measurement model, and (2) overall model chi-square test and the other commonly used goodness of fit indices are available for model fit evaluation [68]. We analyzed the data using Mplus [69] and utilized the maximum likelihood method of estimation.

A two-step procedure was adopted to examine the hypotheses. Namely, the measurement model would first be examined to confirm the factor structure within each measure. In other words, we could confirm whether a particular observed variable or indicator (e.g., the item score from the preservice teachers) belonged to a hypothesized latent factor through the use of confirmatory factor analysis (CFA). After confirming the factor structure for each measure, we then created the sum score for the corresponding measure and used these scores for the hypothesized structural model.

4.1. Measurement Model

The fit of each measurement model as presented in Table 2 was evaluated based on the overall model chi-square test and other commonly used fit indices, including CFI, SRMR, and RMSEA [68,70]. Additionally, we examined both standardized factor loadings and reliability to further validate the construct structure. According to Hu and Bentler [70], models with a CFI (Comparison Fit Index) value close to 0.95 and both SRMR (Standardized Root Mean Square Residual) and RMSEA values close to or smaller than 0.08 can be viewed with adequate fit. As presented in Table 2, all the measurement models met the above guidelines and fit adequately to the data.

Table 2. Results of measurement model analysis.

Variables	Model Fit Indices	Reliability	Factor Loadings
Instructional Time Q1–Q4 EX: Q4. I appreciate having multiple opportunities (exercises) to practice in Second Life prior to giving my final problem-solving lesson.	Chi-square = 0.00 df = 0, p = 0.00 N = 59 CFI = 1.00 SRMR = 0.00 RMSEA = 0.00	0.66	0.40–0.83
Presence Q5. I had a sense of being present or being there in the virtual learning spaces, when I participated in the various SL activities.	N/A		N/A
Engagement Q6. The experience of engaging in exercises and giving my lesson in SL allowed me to engage with middle grade student avatars in a meaningful way.	N/A		N/A
Instructional Effectiveness Q7–Q9 EX: Q9. I found the Problem-Solving Lesson valuable in allowing me to work with the middle grade student avatars to develop my teaching skills.	Chi-square = 0.00 df = 0, p = 0.00 N = 59 CFI = 1.00 SRMR = 0.00 RMSEA = 0.00	0.75	0.47–0.99
Personal Mathematics Teaching Efficacy (PMTE Subscale on MTEBI) 13 Items	Chi-square = 41.21 df = 27, p = 0.22 N = 59 CFI = 0.93 SRMR = 0.07 RMSEA = 0.05	0.75	0.45–0.77
Mathematics Teaching Outcome Expectancy (MTOE Subscale on MTEBI) 8 Items	Chi-square = 12.06 df = 13, p = 0.52 N = 59 CFI = 1.00 SRMR = 0.03 RMSEA = 0.00	0.72	0.44–0.80

Additionally, convergent validity could be examined by the significance of the factor loadings which showed the magnitude of the relation between the individual item and the corresponding construct [68]. As shown in Table 2, all the observed variables were significantly loaded on the corresponding constructs ($p < 0.01$), with factor loadings ranging from 0.40 to 0.99. This result provided another support for the high construct validity of the factors. Reliability coefficients (alpha) were also calculated for the score of each of the three constructs. Three of the four coefficients were above the generally acceptable level of 0.70. On the other hand, for the single-item measure, coefficient alpha could not be computed. Hair and colleagues [71] suggested that the use of the single-item measure can be determined based on the researcher's best judgment. Hence, all the measures used in the hypothesized structural model were deemed to have an acceptable level of construct validity.

4.2. Structural Model

The results of the hypothesized structural model are shown in Figure 4. According to the fit statistics, this model fits the data adequately (i.e., CFI = 1.00, RMSEA = 0.00, SRMR = 0.02). Moreover, all the model estimates were statistically significant, and the standardized coefficients ranged from 0.27 (close to the medium effect size as proposed by Cohen) to 0.60 (above the recommended large effect size). All the hypotheses of direct relationships (H1–H5) and of indirect relationships (H_{01}–H_{04}) were supported. The model explained the substantial amount of variance based on Cohen's (1988) guideline: 79% of the variance ($R^2 = 0.79$) in instructional effectiveness, 66% of the variance ($R^2 = 0.66$) in engagement, 20% variance ($R^2 = 0.20$) in the teaching self-efficacy, and 8% ($R^2 = 0.08$) in outcome expectancy. The instructional time strongly and positively influenced engagement ($\beta = 0.33$, $p < 0.001$). Presence was strongly related to engagement ($\beta = 0.60$, $p < 0.001$), and engagement was strongly related to instructional effectiveness ($\beta = 0.45$, $p < 0.001$). The variable of instructional effectiveness was strongly and positively related to teaching self-efficacy ($\beta = 0.45$, $p < 0.001$) and outcome expectancy ($\beta = 0.28$, $p < 0.001$). All the hypotheses of indirect relationships H_{01}, H_{02}, H_{03} were supported. Engagement mediated the relationship between instructional time and instructional effectiveness ($\beta_{\text{instructional time engagement instructional effectiveness}} = 0.15$, $p = 0.01$) and presence ($\beta_{\text{presence engagement instructional effectiveness}} = 0.27$, $p = < 0.001$). Instructional effectiveness mediated the relationship between engagement and teaching self-efficacy ($\beta_{\text{engagement instructional effectiveness self-efficacy}} = 0.20$, $p = 0.01$) and outcome expectancy ($\beta_{\text{engagement instructional effectiveness outcome expectancy}} = 0.13$, $p = 0.05$).

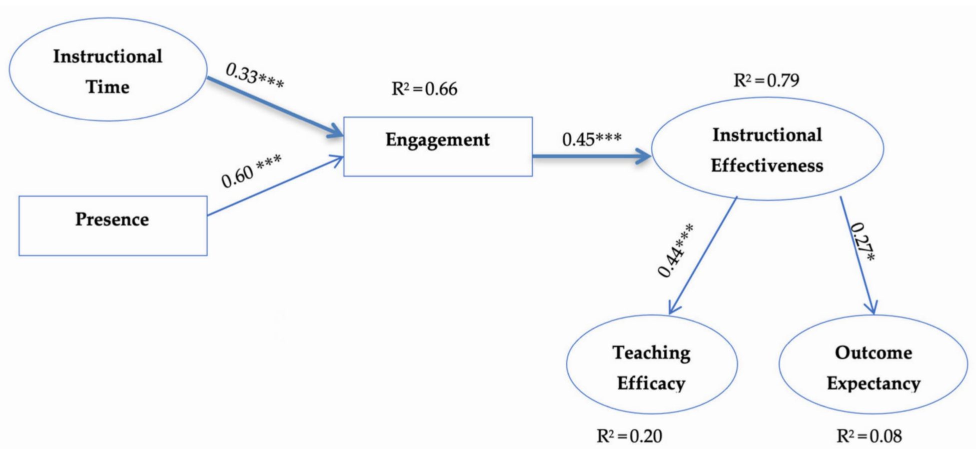

Figure 4. Structural equation modeling of the constructs. * Coefficient is significant at the 0.05 level (2-tailed). ** Coefficient is significant at the 0.01 level (2-tailed) *** Coefficient is significant at the 0.001 level (2-tailed).

5. Discussion

Developing an immersive classroom space to support practice-based teaching experiences for preservice teachers was a goal of our work. We sought to design classroom teaching simulations that could provide focused time for preservice teachers to interact fully in their problem-solving lessons with middle grade student avatars. Multiple exercises in the simulated classroom environment and learning spaces took place prior to the final delivery of their problem-solving lessons. We were able to confirm both the impact of preservice teachers' sense of presence and the impact of instructional time on their perceptions of meaningful engagement (H1, H2) during their teaching sessions. Further, we found that engagement impacted the overall instructional effectiveness (H3) and, subsequently, their mathematics teaching efficacy (H_{03}) and outcome expectancy (H_{04}) beliefs. The study also found statistically significant and positive relationships between instructional effectiveness and teaching self-efficacy (H4), as well as instructional effectiveness and outcome expectancy (H5).

As we unpack our findings, instructional time had a strong and positive effect on preservice teachers' perceptions of meaningful engagement with the middle grade student avatars (H1). Our findings confirm previous research on the importance of both instructional time and presence in impacting engagement (H1, H2) and instructional effectiveness (H_{01}, H_{02}). Holt and Brockett [54], in their study, explained that technology use may be improved by employing teaching methods or pedagogies with undergraduates that encourage time spent with technology (p. 2080). Sitzmann's [61] investigation of the instructional effectiveness of simulation games indicated that the time spent in the environment (or instructional time) is an important factor that can impact instructional effectiveness [61]. Sitzmann also notes that trainees learned more when a simulation game was a supplement to other instructional approaches rather than stand-alone instruction. Additionally, the direct and indirect effects of instructional time on engagement and instructional effectiveness extend the preliminary findings from Davis, Chien, Brown and Kulm [55], where preservice teachers reported a strong need for increased time during the practice teaching sessions. The results from the current inquiry suggest that providing more time for the sessions in the virtual classroom had a positive effect on preservice teachers' overall perceptions related to meaningful engagement and instructional effectiveness.

An underlying purpose of our instructional design work was to provide an authentic setting where preservice teachers felt present in the virtual classroom and were fully immersed in their teaching [49,72]. We hypothesized that if we met these goals the simulated teaching sessions might be more effective. Our findings from the current inquiry help to support this view. The effect of presence in the model confirms our hypotheses (H2, H_{02}), along with previous research on the importance of experiencing the sense of being present in the virtual space or MUVE. Previous work suggests that the more immersive the virtual environment, the greater sense of presence participants are likely to experience [27]. How well the user is immersed in the environment and the level of control the user experiences is essential for authentic experiences in MUVEs [49,72]. We designed a virtual classroom environment that reflects these factors to a great extent. We believe that the authentic experiences in the virtual classroom support, in part, the PSTs' perceptions of presence. Each preservice teacher was fully in control of the classroom environment. During their problem solving lessons, for example, they used resources in the classroom, like advancing and displaying their lesson presentation slides on the large screen.

Previous studies have found that presence can also be enhanced through engagement or interactivity with other users [50,53]. We believe that the interactive nature of the teaching sessions may have strengthened the PSTs' sense of being present in the classroom. We were also able to confirm the impact of preservice teachers' sense of presence on their perceptions of meaningful engagement during their teaching sessions (H2). Throughout their lessons, preservice teachers discussed and worked out mathematics problem-solving steps on the SmartPodium tablet that were simultaneously displayed on the large screen in the SL classroom. They also responded to students' questions and addressed any misconceptions. This authentic engagement may be related to preservice teachers' beliefs about the effectiveness of their teaching sessions. Their approaches may have also been substantiated by the student avatars indicating their understanding of the content through verbal cues and gestural cues, e.g., "I think I see what you mean, I'm almost with you" or "I get it".

Similar to the findings from Cheong [43], the results from the current study suggest that preservice teachers can gain valuable and meaningful practice in their teaching through engagement in classroom simulations. Cheong found that collaborative practice teaching was a more effective approach to practice teaching than individual approaches. Throughout the problem-solving course, preservice teachers had opportunities to practice with the middle grade student avatars and their peers. They also had multiple opportunities to reflect on their teaching as well as critique and provide feedback to their peers. We propose that the overall engagement and perhaps these combined experiences have bearing on our findings. In addition, consistent with the Dalinger, Thomas, Stansberry, and Xiu [21] findings, the preservice teachers were able to observe the lessons of their peers prior to engaging with the avatars in their lessons; they learned from their peers' mistakes and that helped them improve their encounters as well (p. 9). Additionally, Hixon and So [73], in their discussion of the benefits and limitations of traditional and technology-enhanced, virtual field experiences, highlighted that "creation of shared experiences" and "promoting reflectivity" were among the benefits of technology-enhanced/virtual experiences (p. 300).

We also note that the results confirmed the hypotheses of a direct positive relationship between instructional effectiveness and mathematics teaching efficacy (H4), as well as outcome expectancy (H5). Indirect relationships between engagement and both mathematics teaching efficacy (H_{03}) and outcome expectancy (H_{04}) were also confirmed. This finding resonates with the finding in other studies that have shown that familiarity with the virtual environment and, importantly, the act of teaching the avatars [18], as well as peer observations, impacted preservice teachers' self-efficacy beliefs [64]. We believe that this begins to center the intent of our virtual classroom simulation teaching experiences. More specifically, this aligns with our findings in the study. The positive effect of instructional effectiveness and engagement on PSTs' mathematics teaching efficacy and outcome expectancy beliefs are encouraging. When preservice teachers felt present in the space and had time to immerse themselves in successful practice teaching, that resulted in positive outcomes (e.g., meaningful engagement in the virtual classroom lessons, teaching efficacy, and the belief that their effective teaching could translate to their students' success in mathematics).

Moreover, Puvirajah and Calandra [20] offered that engaging preservice teachers in simulations combined with reflection can provide opportunities for novice teachers to feel and act like teachers, described as the embodiment of a teacher. This is not a minor point. We agree with Puvirajah and Calandra: as preservice teachers are engaged in virtual world practice-based experiences, "learning is not just how to do things, but they can start down a path of *learning to be*" (p. 26). Furthermore, the importance of engagement in simulations that reinforce subject matter content and pedagogy [8], and ultimately mathematics teaching efficacy, cannot be overemphasized. A strength of the project and the research reported here is the examination of preservice teachers' perceptions of simulation experiences in a MUVE and the relationship to their mathematics teaching efficacy and outcome expectancy beliefs. These findings are of import to teacher educators who continue to explore ways to design authentic experiences, that can impact preservice mathematics teachers' self-efficacy prior to their field experiences or subsequent classroom teaching. Providing a practice setting to allow preservice teachers to make the essential connections between theory and practice is invaluable. A continuation of this line of inquiry is worth pursuing.

6. Conclusions

The hypothesized structural model which examined preservice teachers' experiences engaging in classroom teaching simulations in a virtual world was supported in this study, but we collected all data from two semesters of undergraduate students enrolled in a problem-solving course at the study site. We therefore suggest that the results might not be generalizable to preservice teachers in other learning contexts at other sites. We propose that additional studies be designed to investigate other settings for preservice teachers engaging in Second Life (or comparable platforms) if generalizability is a goal. Despite these limitations, this work contributes to an evolving research agenda. Evidence suggests that practice-based teaching simulations for preservice teachers can be structured effectively in virtual worlds (e.g., [4,8,17,43,55,74,75]). Of note, the use of teaching simulations in mathematics teacher education has been sparse. Simulation platforms like Second Life or next generation platforms [17] can play a role in providing pre-practicum experiences in mathematics teacher education and across other teacher education disciplinary foci.

Sustained research to evaluate which factors in simulation design and utilization for preservice teachers yield the most efficacious outcomes is recommended. Illustratively, further investigation of optimal conditions for eliciting users' sense of presence, or optimal instructional time for classroom simulation engagement, as suggested by Hudson, Voytecki, and Zhang [34], is needed. Moreover, an important direction following the work described here is examining the extension of PSTs' teaching efficacy to transferability. Billingsley, Smith, Smith, and Merritt [75] suggest that research is needed to examine the extent to which learning in virtual environments transfers to real classrooms (p. 85). Billingsley et al., in their review study on using immersive virtual reality in teacher education, aptly note that we must take care to design environments that attentively simulate the various dimensions of real classrooms (p. 85). Future investigations should focus on the extent to which preservice teachers' mathematics teaching efficacy achieved from engagement in simulations ultimately transfers to their classroom.

Furthermore, the work described here occurred before the onset of the COVID-19 pandemic. However, as we reflect on our approaches and findings in the current study, we consider them in light of the new realities that permeate our education ecosystem. The initial move to emergency remote learning in 2020 was stunning. The implications are far-reaching [76–78] and undoubtedly have not been fully realized. However, two realities are particularly related to the work reported here. First, the loss in learning opportunities and gaps for some PreK-12 students have been and continue to be amplified amid the COVID-19 pandemic [79]. Second, like so many areas within this ecosystem, teacher preparation, including the accessibility of early or clinical field experiences for preservice teachers, may continue to be impacted [80]. It is within this reality that we further consider the relevance of our work. There is an opportunity to focus on novel effective designs of virtual experiences in addition to field placements that require face to face interaction. Such experiences can be designed as early practice-based experiences that may augment or better prepare novice teachers for field placements. We proffer that utilizing simulations in virtual worlds or MUVEs can and should be further explored and leveraged, now more than ever. This line of research can inform approaches now and also in post-pandemic or future praxis. Moreover, those of us who have been working in these spaces have the unique opportunity to lead and support others in such efforts.

Our approach here was to situate learning within a virtual classroom setting. We agree with the assertion by Kuznetcova and Glassman [22] that MUVEs have the potentiality for "shifting the balance of educational processes as a whole away from the 'front of the class' instructor/centralized classrooms and towards a more distributed, non-hierarchical, non-linear shared learning environment" (p. 401). In future research, we would like to further explore designs in MUVEs that extend the learning context beyond the front of the classroom which was mainly the context for the work discussed in this article. We have made some steps in this direction in the design of learning activities in our *Music Math Park*, that is also available in Second Life® and has been described fully by Davis, Phillips and Kulm [4]. Furthermore, much like Kuznetcova and Glassman, we too ponder similar questions as we conclude this article. Do we want to teach students (preservice teachers in this case) how to use these kinds of virtual environments to engage in a variety of less utilized or emerging participatory approaches? We believe that the potential of MUVEs to provide an effective space for practice-based teaching experiences and learning (e.g., active, experiential, distributed) can be more fully realized, as many have suggested, particularly if preservice teachers have various successful experiences engaging in these virtual spaces as both teacher and learner.

Author Contributions: Conceptualization, T.J.D.; methodology, T.J.D., Z.M. and O.-M.K.; formal analysis, T.J.D. and Z.M.; writing—original draft preparation, T.J.D.; writing—review and editing, T.J.D.; project administration, T.J.D.; All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Science Foundation grant number [1020132].

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board at Texas A&M University (Ref. No. 068103) for studies involving humans.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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