Received: 13 June 2022 | Accepted: 4 December 2022

DOI: 10.1111/bjet.13296

ORIGINAL ARTICLE

British Journal of Educational Technology BERA

Improving teaching practices via virtual reality-supported simulation-based learning: Scenario design and the duration of implementation

Chih-Pu Dai[1] | **Fengfeng Ke**[1] | **Zhaihuan Dai**[2] | **Mariya Pachman**[3]

[1]Department of Educational Psychology and Learning Systems, Florida State University, Tallahassee, Florida, USA

[2]Innovative Education, University of South Florida, Tampa, Florida, USA

[3]Center for Academic Technology, Texas A&M University, Kingsville, Texas, USA

Correspondence

Chih-Pu Dai, Department of Educational Psychology and Learning Systems, Florida State University, 1114 West Call Street, Tallahassee, FL, USA.
Email: cdai@fsu.edu

Funding information

National Science Foundation, Grant/Award Numbers: 1632965, 2110777

Abstract

Graduate Teaching Assistants (GTAs), or student instructors, are the crucial force in college for undergraduates' learning in Science, Technology, Engineering and Maths (STEM) disciplines. However, professional development of student instructors is often neglected. Providing adequate and appropriate teacher training for student instructors is a critical challenge. When the technology is available, open-source non-immersive virtual reality (VR) can be a cost-efficient and accessible platform for teacher training. Empirical research of designing and implementing VR for the training on teaching knowledge and skills development is inconclusive and thus warranted. In this ex post facto study, we investigated VR-based teacher training with 33 STEM student instructors to explore the effects on the participants' virtual teaching practices of two design factors: (1) the simulated teaching scenario and (2) the duration of training program implementation. We analysed 7604 event logs from the recordings of their virtual teaching sessions. The results of ordinal logistic regression analyses showed two factors contributed to higher odds of appropriate teaching actions. The first is the simulated scenarios that induced a more dynamic balance of domain-specific and pedagogical knowledge for decision making in teaching; the second is the teacher training program with a longer duration.

KEYWORDS
scenario designs, simulation-based learning, teacher education, virtual reality

Practitioner notes

What is already know about this topic

- Teacher training, especially for college graduate teaching assistants in Science, Technology, Engineering and Maths (STEM) disciplines, is a key for the success of undergraduate students in STEM.
- Virtual reality (VR)-supported simulation-based learning has been found effective for enhancing knowledge and skills development in diverse settings, including when being used for teacher training.

What this paper adds

- A guiding framework for the investigation of scenario design and duration of implementation in VR-supported teacher training.
- VR scenarios that encourage more dynamic balance of domain-specific and pedagogical knowledge for decision making in teaching have higher odds for appropriate teaching acts.
- A longer duration of program implementation in VR can result in higher odds for appropriate teaching acts.

Implications for practice

- We should carefully consider appropriate scenario designs in VR to enhance dynamic decision making and interactivity in simulation-based teaching practices for teacher training.
- We encourage extended duration of VR teacher training programs to facilitate teachers' observant, autonomous and attentive VR-based micro teaching practices.

INTRODUCTION

Teacher training, focusing on college Graduate Teaching Assistants (GTAs), or student instructors, in Science, Technology, Engineering and Maths (STEM) disciplines is important for undergraduate students' knowledge acquisition, application and retention (DeChenne et al., 2012). Although many scholars have advocated the necessity of providing adequate training and support for student instructors in colleges and universities, it is still a critical challenge to implement training programs on teaching that allow the trainees to practice core teaching techniques and skills in in-situ environments with variant teaching scenarios and contexts that meet teachers' needs (Dille & Røkenes, 2021; Rienties et al., 2013). Moreover, a recent literature review on virtual reality (VR)-supported simulation-based learning in teacher education found a limited amount of research despite useful applications (Ledger et al., 2022).

Teaching involves intricate problem-solving processes and dynamic decision making; it entails not only content expertise, but importantly, pedagogical knowledge (Postareff et al., 2007). VR environments have demonstrated promises for learning of complex and context-rich problem solving (Chernikova et al., 2020). In non-immersive VR learning environments, VR's ease of access and versatility in simulating epistemic practices or in replicating authentic settings make it a relatively more cost-effective alternative than face-to-face options for professional development (Dubovi et al., 2017; Ke, Pachman, et al., 2020; Merchant et al., 2014). Moreover, VR-supported simulation-based learning can address the needs of regular and emergency virtual teaching and learning (Frei-Landau & Levin, 2022). As such, applying *VR-supported simulation-based learning for teacher training* has attracted attention of educational practitioners and researchers in teacher education (Dalgarno et al., 2016; Fowler, 2015; Ke, Dai, et al., 2020; Ke, Pachman, et al., 2020).

Despite the increasing interest and preliminary findings on the feasibility of VR-based teacher training, research on the design and application of sustainable VR for the training of teaching knowledge and skills is still inadequate——particularly for student instructors in higher education settings. More specifically, studies investigating the scenario design and duration of implementation in relation to VR-supported teaching practice are still scarce and inconclusive in the literature (Fromm et al., 2021).

Framework for designing VR-supported simulation-based learning experience for student instructor training

VR-supported simulation-based learning, differs from other forms online platforms, affords immersion and enables human users to perceive and experience a sense of presence (Slater & Wilbur, 1997). *Immersion* is "the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding, and vivid illusion of reality to the senses of a human participant" (Slater & Wilbur, 1997, p. 3); whereas *sense of presence* is "a state of consciousness, the (psychological) sense of being in the virtual environment" (Slater & Wilbur, 1997, p. 4). Depending on the displays and systems, immersion and sense of presence afforded by VR can vary.

VR can be applied in different forms such as immersive VR, mixed reality and desktop VR (Dai & Ke, 2022; Merchant et al., 2014). We adopted desktop VR as "a 3-D virtual environment generated on a computer monitor, which can be explored interactively by using computer equipment such as keyboard, mouse, joystick or touch screen, and headphones" (Makransky & Petersen, 2019, p. 16). In addition to desktop VR that we endorsed in this study, immersive VR with Head Mounted Displays (HMDs) is another type of application that is of interest to education researchers and practitioners. We adopted desktop VR for its easy accessibility and high cost-efficiency in comparison to immersive VR (Dubovi et al., 2017).

Immersive VR were perceived to be able to provide higher immersion and fidelity (Raut, 2018) as well as embodied practices (Makransky et al., 2021) whereas desktop VR has been reported to offer strong sense of presence and sense of control that could promote learning (Dubovi et al., 2017). In support, Raut (2018) reported that desktop VR resulted in higher "perceived doing rather than solely experiencing" than immersive VR.

It remains inconclusive as to whether immersive VR or desktop VR is more beneficial for learning. Specifically, Klingenberg et al. (2020) found the benefits of using immersive VR for learning while other studies suggested that immersive VR is no better than desktop VR or other simulations (Makransky et al., 2021; Makransky & Petersen, 2019) in enhancing learning. With specific learning outcomes (eg, spatial learning), desktop VR was found to be more beneficial than immersive VR with HMDs (Srivastava et al., 2019). Further, Jensen and Konradsen's review (2018) advised that immersive VR's usefulness is no superior to non-immersive VR except for when being used for the training of, for instance, visual scanning and observations or emotion management. Compared to desktop VR, VR with HMDs can also be less equal for users in terms of accessibility due to costs and higher risks of induced motion sickness for some users.

In alignment with the purpose of this study, we considered cost-effectiveness, accessibility and the literature on effectiveness of each VR environment (Ke & Xu, 2020). In result, we adopted desktop VR as the tool for VR-supported simulation-based training and learning of teaching.

Scenarios and duration of implementation for VR-supported teaching and learning

Prior studies have articulated alternative research frameworks for teaching and learning in VR (Dalgarno & Lee, 2010; Fowler, 2015). However, empirically-investigated theoretical propositions for designing VR-supported simulation-based learning for student instructor regarding *scenarios* and *duration of implementation* are vastly missing.

Propositions for the *design of scenarios* in VR-supported simulation-based learning can be drawn from prior research of representational fidelity and learner interaction (Dalgarno & Lee, 2010), authentic and contextualized learning activities (Ke et al., 2016), as well as the *designing for learning* framework (Fowler, 2015, p. 420). Specifically, representational fidelity and learner interaction can contribute to "afforded learning tasks" (Dalgarno & Lee, 2010, p. 15). Authentic and contextualized learning activities (Ke et al., 2016) determine in-situ, authentic and high-fidelity practices. Locus of control decides whether it is instruction- or inquiry-based learning experience (Fowler, 2015).

In terms of learner interactions, sense of presence, interaction with the environmental features (such as virtual agents and objects) and different levels of interactivity can enact different degrees of *dynamic decision making* (Dalgarno & Lee, 2010; Fowler, 2015; Ke et al., 2016). These constructs support the formulation of realistic scenarios in VR (Dalgarno & Lee, 2010; Fromm et al., 2021; Ke et al., 2016) (see Figure 1).

The *duration of implementation* in VR-based learning is closely associated with the level of practice and the length of experience. It is suggested that the longer the learner experiences in the VR-based learning activities, the more opportunities arise for higher-level knowledge developments and skill applications (cf. Kolb, 1984). On the other hand, it is possible that a longer duration will reduce task involvement due to reduced novelty effect of VR or lead to motion sickness as well as fatigue, thus reducing the learning effectiveness of VR-based training (eg, Freina & Ott, 2015; Kourtesis et al., 2019; Sharples et al., 2008). Although motion sickness is more significant in VR with HMDs compared to desktop VR, desktop VR can still induce significantly higher motion sickness of disorientation after the experience (Sharples et al., 2008).

Other theoretical perspectives that may inform about the scenario design and duration of implementation for VR-based learning are experiential learning (Kolb, 1984) and constructive views of learning (eg, Piaget, 1964; Steffe & Gale, 1995). According to Kolb (1984), learning is a process that is situated in the transformation of experience; and *a continuous adaptation* to new knowledge and inputs is necessary. That is, a constant duration of involvement in transformative experience is critical for learning. Nonetheless, whether this perspective holds true for VR-supported simulation-based learning environments is still elusive.

To examine the VR-supported simulation-based learning for student instructor, we focus on appropriate teaching acts enacted by student instructors in VR. The demonstrated teaching acts of the student instructors are suitable indicators of student instructors' teaching knowledge and skill development. Based on Kolb (1984)'s *transformation of experience*, the externalization of teaching knowledge and skills is evidenced by the demonstrated teaching acts. Particularly, these teaching acts are the embodiment of student instructors' content and pedagogical knowledge (Shulman, 1986).

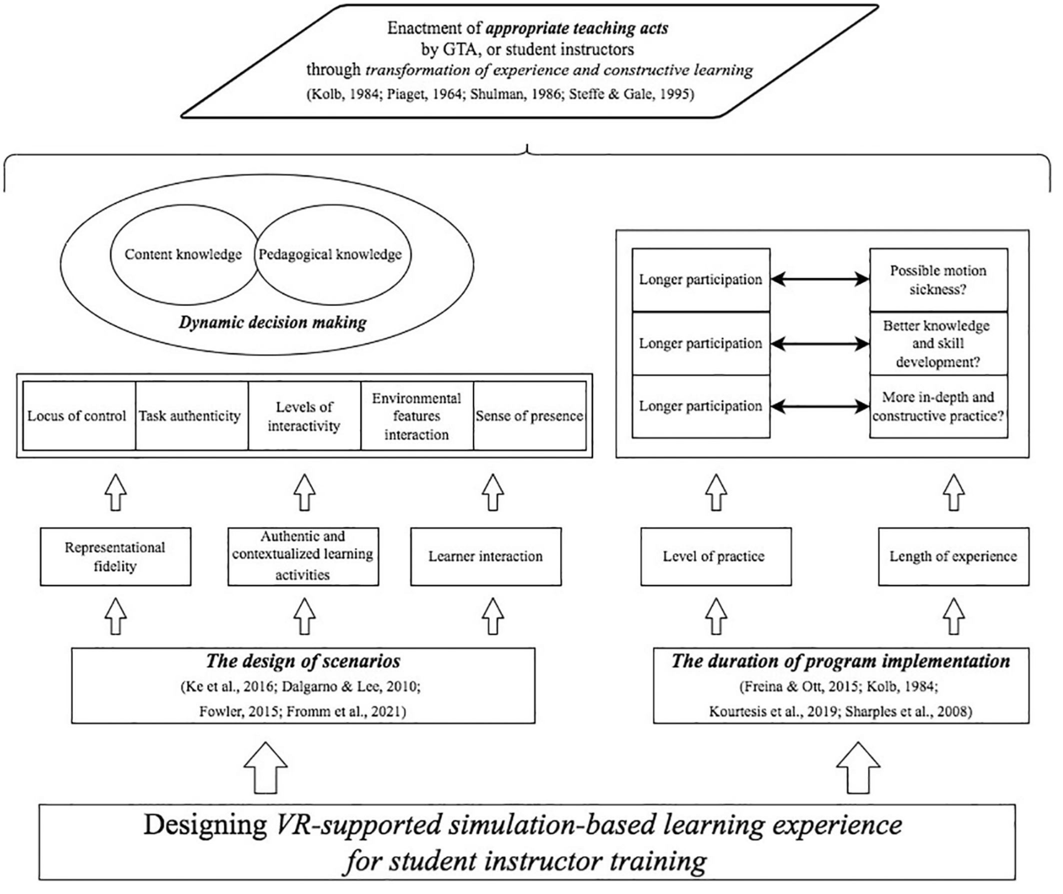

FIGURE 1 A guiding framework: *Designing VR-supported simulation-based learning experience for student instructor training*.

Although some recent VR studies started to examine the potential impacts of scenarios and the duration of a VR intervention (Chernikova et al., 2020; Fromm et al., 2021), empirical studies are still warranted to investigate the impacts of scenarios and the implementation duration in a VR-based learning intervention designed with a guiding learning framework (Radianti et al., 2020). We based our investigation and design conjectures on the aforementioned scholarship and proposition (see Figure 1). Specifically, we investigate *the design of scenarios* and *duration of implementation* as two predicting variables for the outcome of *appropriate teaching acts*.

Factors influencing learning experience in virtual reality

Scenario design: Tasks/activities design and environmental features

Scenario designs in VR refer to the design of authentic tasks/activities within a simulated scene in which learners interact with virtual agents and environmental objects via their avatars (Bailenson et al., 2008; Fowler, 2015). Sense of presence, especially social presence (ie, awareness of others being in VR), can be increased by immersing learners in the interactive experience with the virtual agents and other learners in VR-based learning environments

(Sinatra et al., 2021). It is suggested that a scenario should be authentic and interactive to foster active experimentation in VR-based learning environments (Fromm et al., 2021). Scenarios can differ in different levels of interactivity, via the design of activities and virtual agents that frame varied VR-based learning experiences and hence foster dynamic decision making to different degrees.

There are two types of VR-based learning scenarios for student instructors examined in this study. The first (Domain-Specific Knowledge-Pedagogical Knowledge, *DSK-PK scenarios*) depicts dynamic decision making balanced between domain-specific knowledge and pedagogical knowledge training for student instructors. The second (Domain-Specific Knowledge, *DSK scenarios*) focuses on dynamic decision making prioritizing domain-specific knowledge for student instructors. In the DSK-PK scenarios in VR, the acquisition of knowledge is through active interactions, knowledge application and construction (Fromm et al., 2021; Ke, Pachman, et al., 2020). The dynamicity of task and interaction design of these scenarios are aimed to encourage student instructors to practice both domain-specific knowledge and pedagogical knowledge during simulation-based training. However, some studies suggested that the dynamicity of task and interaction may induce cognitive overload for the learners (Ke, Pachman, et al., 2020; Makransky et al., 2021). For example, Ke, Pachman, et al. (2020) indicated that without sufficient time and adequate learner preparation in VR, learners may be overwhelmed by the VR interactive features in addition to the teaching-practice tasks that demand decision making and knowledge presentation. As suggested by Moreno and Mayer (2007), designing learning experiences in VR often comes with the challenges of increasing learning while diminishing extraneous cognitive load. The effects of different scenario designs on this regard is poorly understood.

Scenario design: Virtual agent's role embedded in tasks and activities

Another scenario design feature that could possibly affect the learning outcomes is the role of virtual agents/students embedded in VR learning tasks and activities (Bailenson et al., 2008; Gibbons, 2020; Ke, Dai, et al., 2020; Ke, Pachman, et al., 2020). The roles of virtual students are to provide interactive teaching opportunities and facilitate *adaptive teaching* and *teaching as problem solving* (Dai et al., 2021; Ke, Pachman, et al., 2020). Similarly, Gibbons (2020), put virtual agents as learning companions, argued that they "must be able to carry on challenging and evaluative discourse of some form with the learner" (p. 2805). The design of virtual students in the VR scenarios can also impact the dynamicity of the interactions. Adaptive virtual students (in *DSK-PK scenarios*) can prompt student instructors to seek alternative instructional strategies and to respond to students' needs, which is different from fully pre-programmed virtual students (in *DSK scenarios*) (Ke, Dai, et al., 2020; Ke, Pachman, et al., 2020). However, the differences of virtual agents in the scenarios for enacting teaching practices in VR are still ambiguous.

Duration factor: Time increments in program implementation

The associations between the duration of participating in VR and performance outcomes are inconclusive. Regarding the duration of VR implementation, some scholars argued that a VR-based training program should be adopted for only a limited period of time (Freina & Ott, 2015) whereas others found that learning effectiveness is positively correlated with the length of a VR intervention (Chernikova et al., 2020). Continuous participation is critical for the transformation of experience (Kolb, 1984). Early instructional theory also suggested that time is a critical factor in learning experience (Carroll, 1963). Although continuous participation in learning is considered important, Virtual Reality Induced Symptoms and Effects (VRISE), such as nausea and/or fatigue, can cause confliction with this learning principle (Kourtesis et al., 2019; Sharples et al., 2008). While Sharples et al. (2008) found that participants in VR with HMDs have a higher possibility of being prone to VRISE than with the desktop counterpart, desktop VR can still induce significant VRISE post intervention. Research examining the relations between duration and learning in desktop VR is nevertheless limited.

In a recent meta-analytic review of simulation-based learning in higher education, Chernikova et al. (2020) reported that longer rounds (or sessions) of training could result in stronger effects on learning. Their review, however, indicated that there is a scarcity of studies exploring duration for the training on teaching skills development. Contrary to Chernikova et al. 's (2020) finding that favours longer periods of participation in VR for learning, Araujo et al.'s (2014) study in medical training with VR suggested that shorter duration is better in terms of surgical skill performance. Hence, the best practices are still inconclusive with regard to the performance outcomes associated with duration in VR-supported simulation-based learning.

Teaching performance in VR

According to Bailenson et al. (2008), actions in VR are continuous observables that can be recorded and archived to inform the learning systems design. In other words, participants' actions in a simulated teaching scenario can be indicators of the effectiveness of teaching training in VR. Moreover, behaviours have been used to evaluate the effectiveness of teaching performance as it reflects the appropriateness of interactions between the environment (ie, the students and the classrooms), the teacher's competencies and teaching tasks (Korthagen, 2004). The literature has classified appropriate teaching acts as inquiry or questioning (eg, Capraro et al., 2010; Redfield & Rousseau, 1981), students' performance monitoring (eg, Goldberg et al., 2021), teachers' diagnostic skills (eg, Seidel et al., 2020) and content instruction (eg, Korthagen, 2004).

Preparing student instructors for appropriate inquiry includes training them to be equipped with suitable problem-solving skills to address students' questions as well as the proper questioning habits to promote students' thinking (Capraro et al., 2010). Student instructors' questioning skills are important. Redfield and Rousseau (1981) classified higher cognitive questions and lower cognitive questions and found that higher cognitive questions are more effective than the lower counterpart because they require students to synthesize information to formulate and support the response rather than recall factual information as a response. Furthermore, Kayima and Jakobsen (2020) proposed criteria judging appropriate questioning by teachers. Teachers' questions should be relevant and adequate, structural and sustaining interactions. Inappropriate questions are vague, unclear, biased and unorganized.

Monitoring students' performance is another facet of appropriate teaching acts. An effective student instructor should direct their attention to the students and classroom events instead of focusing on whiteboard, slides or textbooks (Wolff et al., 2016). Goldberg et al. (2021) analysed video materials and found that novice student teachers were more likely to focus on students' noticeable on-task learning behaviours. In contrast, misbehaving off-task learning behaviours were often neglected. Similarly, Huang et al. (2021) revealed that, in VR classrooms, student teachers tend to put less effort in responding to students' disruptions that are complex. The studies pointed to the training needs in VR for novice student instructors to equip with observation skills detecting students' learning progress to maintain a pleasant and productive learning environment/atmosphere.

Teachers' diagnostic skills are also crucial for teacher training because students' cognitive, motivational and affective states are preconditions that affect learning (Kuo et al., 2021). Discerning and judging behavioural cues to react appropriately to students' underlying states determine teachers' follow-up adaptive pedagogical strategies (Seidel et al., 2020). However, novices are prone to misjudgment of students' underlying states (Seidel et al., 2020) thus possibly leading to inappropriate teaching acts.

Along with the aforementioned aspects of appropriate teaching acts, the accurate and proper content instruction is equally important. Ferdig (2006) argued the importance of content knowledge in technology-enhanced teaching. However, research connecting how teacher education programs incorporate training with VR and content knowledge for teaching is scarce. Content instruction requires student instructors' content knowledge for teaching; this subject-specific knowledge consists not only subject-matter expertise but also pedagogical knowledge (Shulman, 1986). In other words, student instructors should have a deep understanding of the content to be taught as well as effective representation of knowledge (Van Driel et al., 1998). Representations are especially crucial in STEM learning (Rau, 2017). In VR, appropriate content instruction involves the teaching acts of presenting content knowledge using multiple lecturing aids or forms, such as whiteboard, media board, text-based semiotics and verbal explanations.

Therefore, in this study we evaluate teaching performance in VR by observing appropriate teaching acts, via four indicators: (1) inquiry or questioning, (2) monitoring of students' performance, (3) student instructors' diagnostic skills and (4) VR-afforded instruction with content and pedagogical knowledge. It is hypothesized that the enactment of these teaching acts in VR is closely related to the scenario design and duration of participation in VR-supported teacher training.

METHOD

Research questions and the overall research design

In light of the aforementioned gap in the previous research, the purpose of the current study is to examine whether two factors (ie, *teaching scenarios* and *duration of implementation*) can predict the observed *appropriate teaching acts*. Specifically, the research questions are:

RQ1: What *simulated teaching scenarios* in VR-supported teacher training can predict the odds of *appropriate teaching acts* observed for student instructors?

RQ2: Can longer *duration of implementation* in VR-supported teacher training predict the odds of *appropriate teaching acts* observed for student instructors?

We adopted an ex post facto research design in this exploratory study to examine the associations between (1) teaching scenarios and desired teaching performance, (2) duration of implementation and desired teaching performance. In ex post facto design, "the researcher takes the effect (or dependent variable) and examines the data retrospectively to establish causes, relationships or associations, and their meanings" (Cohen et al., 2007, p. 266). In this ex post facto study, we conducted logistic regressions to examine the associations between the two predicting variables (ie, teaching scenarios and duration of implementation) and the outcome variable (ie, appropriate teaching acts) in VR.

The VR-supported simulation-based learning environment

The desktop VR learning environment in this study was designed for training student instructors in STEM subjects using *OpenSimulator*, an open-source VR software. It simulates various college teaching contexts. The student instructors were able to navigate the virtual environment and interact with the environmental features using their own avatars. It also includes computer-controlled virtual agents to impose teaching challenges, prompts, and to facilitate the scenario progression. In addition, other environmental design features in the VR world include (1) communication channels through text−/audio-inputs and voice broadcasting; (2) virtual objects (eg, interactive virtual whiteboard and simulators for chemistry and physics experiments); (3) instructional scaffoldings delivered whenever appropriate by predefined scenario sequence or the facilitators (eg, note cards, posters containing reflective teaching tips and a pop-up dashboard).

Aside from these universal features in our VR environment, the only difference between the training sessions in terms of the learning environment is the scenario with content-based tasks/activities. To be specific, the VR learning environment has six teaching scenarios, including (1) Training Arena, (2) Teaching Adaptively, (3) Better Explanation, (4) Office Hour, (5) Problem Solving and (6) Scientific Labs. We simulated authentic teaching settings in the design of the training scenarios. That is, in the scenarios of Office Hour, a conference room setting was designed (see Figure 2); whereas in Scientific labs, we put lab tables, chairs and equipment (see Figure 3); and in Teaching Adaptively, Better Explanation and Problem Solving, lecture-based settings were arranged (see Figure 4).

In the scenario of (1) *Training Arena*, the student instructors were oriented to the VR environment (the baseline scenario for comparison in this study). In the scenario of (2) *Teaching Adaptively*, the virtual agents (acted as virtual students) were designed to have different needs and preferences for learning. Student instructors were prompted to react adaptively to the expressed needs of the virtual students when delivering an instruction. In the scenario of (3) *Teaching with Better Explanation*, the virtual students will challenge the student instructors to use different modes or strategies to explain the current content/topic being taught. For example, the virtual agents would prompt the student instructor to draw a concept map or provide an example to explain the same content/topic better. In the scenario of (4) *Office Hour*, several pre-programmed virtual agents are set up as students with a variety of questions, ranging from the ones on domain-specific assignments/quizzes, grading issues, to

FIGURE 2 An example of an office-hour scenario.

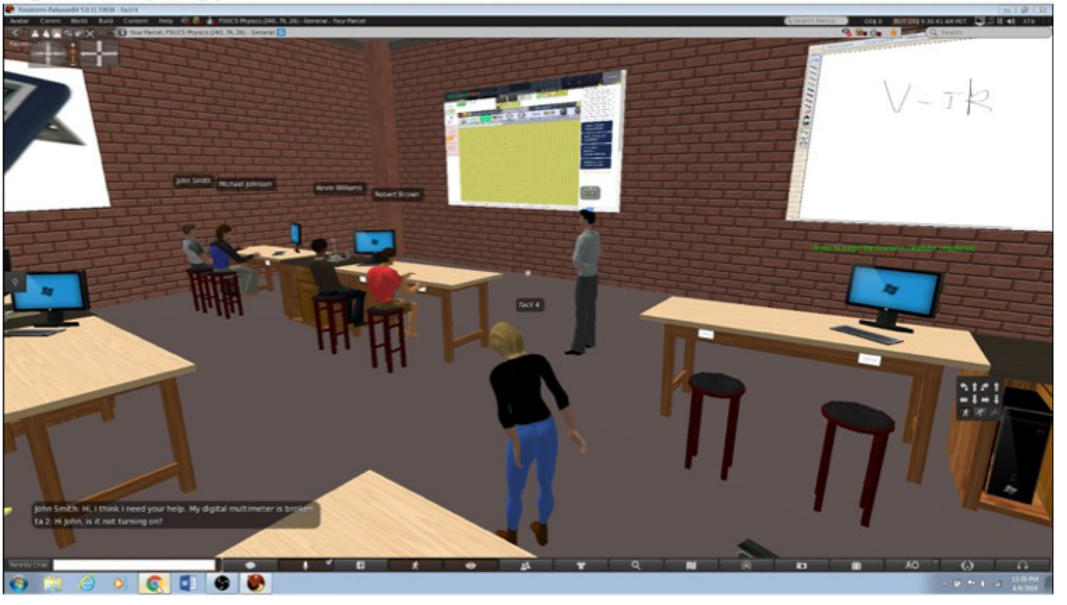

FIGURE 3 An example of a lab-teaching scenario.

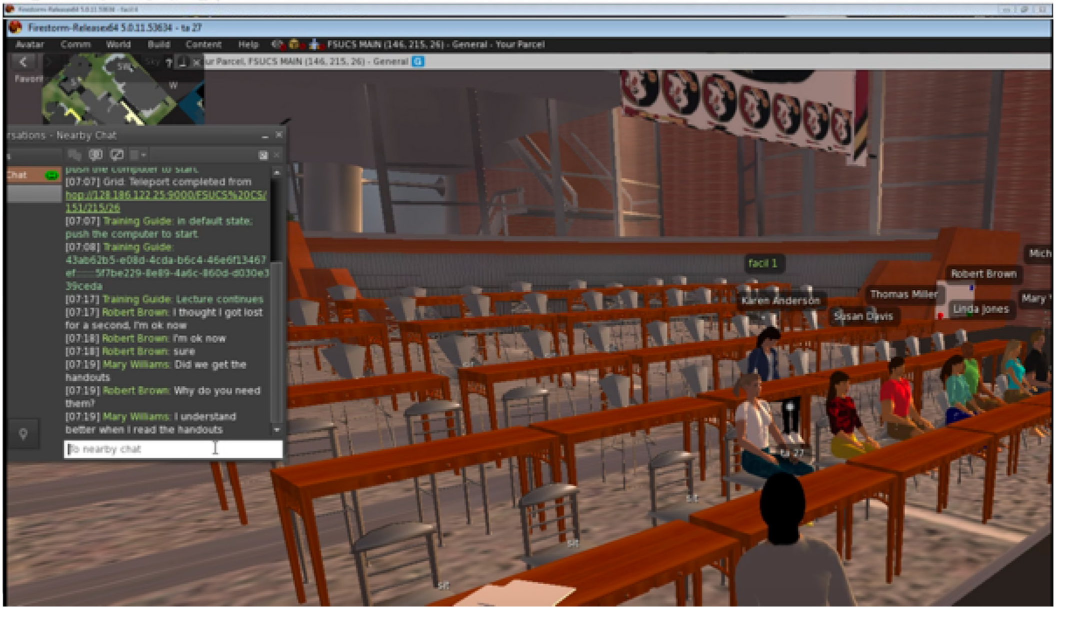

FIGURE 4 An example of the lecture-based scenarios and the text-inputs of programmed virtual agents.

inquiry for study tips. In the (5) *Problem Solving* scenario, student instructors are prompted to teach students how to analyse the problems and learn essential skills for problem solving. Finally, in (6) *the Scientific Labs* (eg, *a physics lab*), the student instructors need to facilitate a lab following the lab protocols that simulate their real-world lab teaching experience.

The aforementioned multimodal interactive features (eg, interactive virtual objects and virtual agents capable of text and voice chats) for dynamic cuing and prompting were purposefully designed to facilitate the training process (Ke, Dai, et al., 2020). Table 1 is a summary of the design proposition governing how the six teaching scenarios were classified in terms of the scenario design types and virtual agents' roles.

Participants, data collection and analysis

We recruited thirty-three student instructors (yielded 7604 behavioural coding logs) from three STEM disciplines in a large research university in the southeastern United States. Specifically, there are seven student instructors from physics, seven from mathematics and nineteen from computer science. These student instructors completed one-on-one training sessions. In total, the student instructors completed 85 training sessions, with 46% of student instructors completing four sessions, 39% completing two sessions and 15% completing one session. Each session was scheduled for two hours. See Table 2 for more detailed information regarding the participants and the sessions.

TABLE 1 A synthesis of the design proposition and the scenarios in this study

Design proposition and the literature	Classification	Scenarios in this study (Note: see "The VR-supported simulation-based learning environment" section for design details and examples)
Task/activity design and interactivity (Fowler, 2015; Fromm et al., 2021; Ke, Pachman, et al., 2020; Makransky et al., 2021)	Dynamic decision making balanced between domain-specific knowledge and pedagogical knowledge training (*DSK-PK scenarios*)	Teaching adaptively Problem solving
	Dynamic decision making prioritizing domain-specific knowledge training (*DSK scenarios*)	Better explanation Office hour Scientific lab
Virtual agent's role (Bailenson et al., 2008; Gibbons, 2020; Ke, Dai, et al., 2020; Ke, Pachman, et al., 2020)	Virtual agents with prompts and needs for a higher level of dynamic decision making	Teaching adaptively Problem Solving
	Virtual agents with prompts and needs for lower level of dynamic decision making	Better explanation Office hour Scientific lab

TABLE 2 Participants and session information

Discipline	Physics	Maths	Computer science
Number of participants	7	7	19
Gender	3 females	1 females	4 females
	4 males	6 males	15 males
Training sessions	12	9	64
Video data	24 hours	18 hours	128 hours
Behavioural coding logs	1377	976	5251

In each session, the participant used a laptop to log in to the virtual learning environment using a Firestorm browser. A facilitator assisted the participant to complete the training in different teaching scenarios designed based on the proposed guiding framework (as presented in Figure 1). The participants received teaching challenges and prompts from the pop-up dashboard, text- and audio-inputs of programmed virtual students and note cards/posters with training information (see Figures 4 and 5). All training sessions were audio- and video−/screen-recorded, which composed the data used in this study.

To analyse the data, we applied a systematic coding approach with the behavioural observation data (Suen & Ary, 1989). The researchers first browsed all the videos and took notes to be familiar with the data. After an open-coding analysis of the videos focusing on the teaching events, we identified relevant and salient categories from the coding results. Then, we held meetings to discuss the videos and define a coding scheme. The codes of the teaching acts were central to the research questions, including "appropriate teaching acts," "failed teaching attempt/inappropriate teaching acts," and "others." Table 3 below describes these codes in detail. The coding scheme was explained and communicated to three coders in a coding training session. The videos were then reviewed and coded by the three trained coders with a behavioural analytic software (see Supporting Information for an example). Among the three coders, two coders earned a doctorate in education and one is a doctoral candidate in education; they have been designing, participating and facilitating the VR teacher training sessions to be competent in evaluating the content and pedagogical teaching practices. The coders first coded sessions of one student instructor from each discipline, with a total of eight sessions coded, including two sessions for one physics student instructor, two sessions for one maths student instructor and four sessions for one computer science student instructor. We calculated the inter-rater reliability. The intra-class correlation coefficient (ICC) indicated a high agreement among the three trained coders (r_{ICC} = 0.97). Next, the coders discussed with the researchers to resolve any ambiguities and disagreements. The coders then individually coded their share of the remaining videos.

In terms of event logs, the data coding process resulted in 7604 coding logs. These event logs composed the dataset analysed in this study. The 7604 logs were imported to

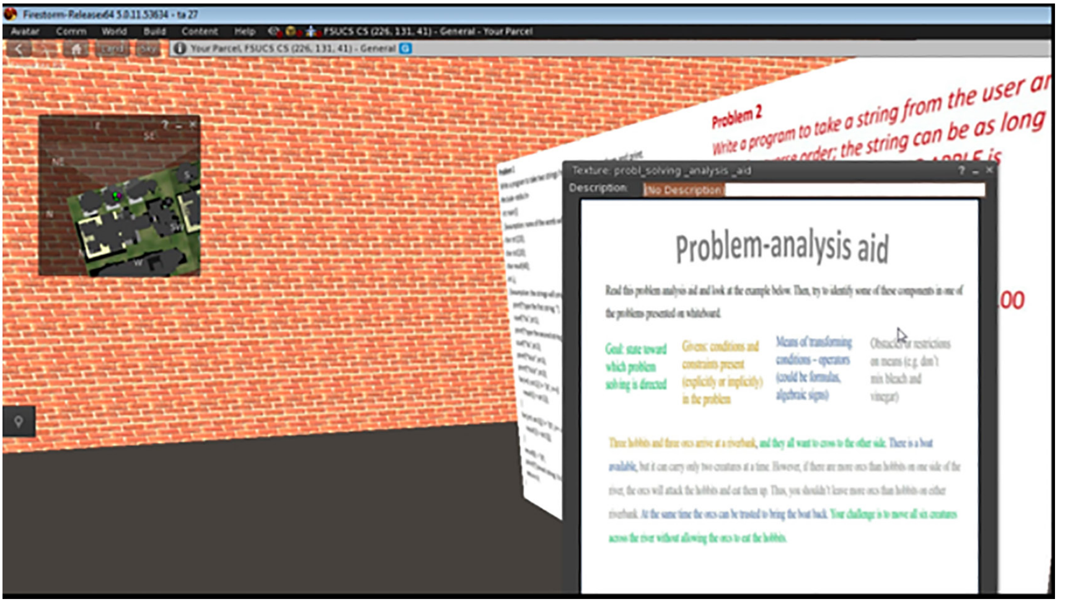

FIGURE 5 An example of posters in a problem solving scenario.

TABLE 3 Teaching acts

Event log	Explanation
Failed teaching attempts/inappropriate teaching acts = 0	The student instructor should perform but did not perform, or did not perform a teaching act appropriately, including inappropriate teaching strategy and domain content; or ignoring the feedback and prompts (eg, virtual students expressing needs for learning) Sample coded instances in the videos are described as follows: "in a Better Explanation scenario, a virtual student (Michael) said 'excuse me,' the student instructor ignored the student"
Others = 1	Teaching events in the videos that were neither *appropriate teaching act* nor *failed teaching attempt/inappropriate teaching act*. Including processing feedback or prompts or seeking help/asking for clarification from the facilitator, as well as debriefing events (formative and summative) with the facilitator Sample codes of the feedback processing are the combinations of the timing of the feedback (ie, during/instant/delayed), the type of the feedback, the agent of the feedback (ie, virtual students, facilitator and objects). Sample codes of the prompts processing are the combinations of prompts from the agent (ie, virtual students, facilitator and the objects) and the type of the prompts (ie, teaching strategy or domain content)
Appropriate teaching acts = 2	The student instructor demonstrated appropriate teaching acts (either voluntarily or satisfactorily followed by prompt/feedback) on the four dimensions: relevant questioning, monitoring students' performance, adjusting follow-up teaching acts in response to virtual students' questions or comments, and accurate content instruction. For example, in a Better Explanation scenario for computer science, a virtual student prompted "can you draw an array?" the student instructor responded and acted: "yes, the initialization of this array is going to be … [drawing an array and explained the size of the array on the interactive whiteboard]" Sample coded instances in the videos are described as follows: "When lecturing, in response to Robert (a virtual student)'s head shaking, CS GTA 15 asked a question to engage the students with real-life experience: 'how do you use Wi-Fi in everyday life?'" or In a physics lab, "following a virtual students' question on a malfunction digital multi-meter, student instructor realized that he did not announce a lab procedure thus he corrected himself by telling virtual students the setting of the equipment"

IBM SPSS version 25.0 for statistical analyses. Given the categorical data and the correlational research questions we sought to address, ordinal logistic regression analyses were conducted (Agresti, 2002; Liu, 2009). The baseline category for the research questions was

Training Arena (RQ1) and session 1 (RQ2) respectively. We dummy coded the following data as a dependent variable in the ordinal logistic regression analysis: "appropriate teaching act" (=2), "failed teaching attempt/inappropriate teaching act" (=0) and other teaching behaviours (=1). Appropriate teaching act, in comparison with other observed events, is considered as an indicator of the most desirable performance outcome of effective teacher training (see Table 3).

There were two predicting variables. For the first research question (RQ1), the independent variable was the simulated teaching scenarios. This variable consists of six predictors, including Training Arena, Teaching Adaptively, Better Explanation, Office Hour, Problem Solving and Scientific Labs. The Training Arena served as a reference category. Thus, we had five ($k-1$) groups to be examined: Teaching Adaptively, Better Explanation, Office Hour, Problem Solving and Scientific Lab. For the second research question (RQ2), the independent variable was the number of training sessions completed, defined as the *duration of program implementation*. The participants completed 4 sessions at the most, hence we coded session 1 (=1), session 2 (=2), session 3 (=3) and session 4 (=4).

RESULTS

Model-data fit was examined in logistic regression to infer justifiable claims (O'Connell & Gray, 2011). We examined the goodness-of-fit for the two logistic regression models in this study. The null hypothesis for the model fit testing was that the data fit the model well. The results showed that the model for RQ1 is $\chi^2(5) = 10.35$, $p = 0.07$, and the model for RQ2 is $\chi^2(3) = 1.89$, $p = 0.60$. According to Cohen et al. (2003), a p-value larger than 0.05 indicates that the expected and observed values in the categories are the same and suggests the model fits the data well. Therefore, the model-fit testing results of this study indicated that both models fit well and supported the null hypotheses for model-data fit testing. In terms of the descriptive statistics, we presented the frequency and percentage for each code of the teaching acts, sessions, and scenarios in Table 4.

Research question 1

An ordinal logistic regression analysis was conducted to investigate the following association: are there any differences in odds of performing *appropriate teaching acts* between participants completing different scenarios? We found that different simulated teaching scenarios contributed to the overall model in the ordinal logistic regression analysis ($p<0.001$, Nagelkerke's $R^2 = 0.01$, 95% CI [0.57, 0.76]). Specifically, the predictors with significant contributions were *Teaching Adaptively*, $\beta_{teach} = 0.40$, $z = 35.66$, $p<0.001$, and *Problem Solving*, $\beta_{ProbSolving} = 0.21$, $z = 10.24$, $p = 0.001$. There was no significant contributions to appropriate teaching acts by DSK scenarios (ie, Better Explanation, Office Hour, and Scientific Lab) (see Table 5).

The estimated odds ratio indicated that compared to participants who completed the *Training Arena*, those who completed the *Teaching Adaptively* scenario demonstrated 1.49 higher odds of performing *appropriate teaching act*, Exp $(\text{Estimate})_{\text{teach}} = 1.49$, 95% CI [1.31, 1.70]. Participants who completed *Problem Solving* had 1.22 higher odds of performing *appropriate teaching act*, Exp $(\text{Estimate})_{\text{ProbSolving}} = 1.22$, 95% CI [1.08, 1.39] (see Table 6).

The results above confirmed that simulated teaching scenarios significantly predicted the enactment of appropriate teaching acts. Particularly, among the 5 scenarios (excluding *Training Arena* as a reference group), there was a significant difference between pairs of (1) the scenario of *Teaching Adaptively* and *appropriate teaching act* and (2) the scenario

TABLE 4 Descriptive statistics of the variables

Variables	Categories	Frequency	Percentage
Teaching acts	Failed teaching attempt/inappropriate teaching acts	480	6.3%
	Others	4283	56.3%
	Appropriate teaching acts	2841	37.4%
Total event logs		7604	100%
Sessions	1	2979	39.2%
	2	1984	26.1%
	3	1537	20.2%
	4	1104	14.5%
Total event logs		7604	100%
Scenarios	Training arena	1164	15.3%
	Teaching adaptively	1452	19.1%
	Better explanation	790	10.4%
	Office hour	1400	18.4%
	Problem solving	1882	24.8%
	Scientific lab	916	12.0%
Total event logs		7604	100%

TABLE 5 OLR model: Different scenarios as the predictors for performance outcome

Predictors (scenarios)	Parameter estimates	SE	Wald	*df*	*p*	95%CI
Teaching arena	0	–	–	0	–	–
Teaching adaptively	0.40	0.07	35.66	1	0.001*	0.27–0.53
Better explanation	0.02	0.09	0.07	1	0.788	−0.14 to 0.19
Office hour	0.04	0.07	0.28	1	0.594	−0.11 to 0.18
Problem solving	0.21	0.06	10.24	1	0.001*	0.08–0.33
Scientific lab	0.02	0.09	0.03	1	0.852	−0.20 to 0.16

Note: The performance outcome is teaching acts (appropriate and failed teaching attempt/inappropriate teaching acts).
*$p < 0.05$, Nagelkerke's R^2 = 0.01.

TABLE 6 The exponentiation of the B coefficient (an odds ratio)

Predictors (scenarios)	Exp(B)	95% Wald confidence interval for Exp(B)
Training arena	1	–
Teaching adaptively	1.49	1.31–1.70
Better explanation	1.02	0.86–1.21
Office hour	1.51	0.90–1.20
Problem solving	1.22	1.08–1.39
Scientific lab	0.98	0.82–1.17

Note: Exp(B) for *Teaching Adaptively* and *Problem Solving* are bolded because they were significant.

of *Problem Solving* and *appropriate teaching act*. Participants who completed these two scenarios (ie, *Teaching Adaptively* and *Problem Solving*) were more likely to demonstrate appropriate teaching acts compared to those who completed *Training Arena*.

In summary, student instructors who completed *Teaching Adaptively* had around 1.5 times higher possibility to perform appropriate teaching acts than those who only completed *Training Arena*. Those who completed *Problem Solving* had about 1.2 times higher possibility to perform appropriate teaching acts than those who only completed *Training Arena*. The rest three scenarios (*Better Explanation*, *Office Hour*, *Scientific Lab*) were not significant in predicting the performance of appropriate teaching acts.

Research question 2

Another ordinal logistic regression analysis was conducted to investigate the following association: will the possibility of *appropriate teaching act* increase as the student instructors participate in more training sessions? The predicting variable, *duration of implementation (sessions participated)*, in the ordinal logistic regression analysis was found to contribute to the model. The ordered log-odds (Estimate) was 0.05, SE = 0.02, $p = 0.03$. Nagelkerke's $R^2 = 0.01$.

The estimated odds ratio favoured a positive relationship of nearly 1.05 fold for every one unit increase in session participated, Exp (Estimate) = 1.05, 95% CI [1.00, 1.09]. To elucidate, with one more session participated in the VR training for teaching practice, the odds of performing appropriate teaching acts for the student instructors are 1.05 times higher than those who did not participate in one more session.

DISCUSSION

The purpose of this study was to investigate the associations between two variables (ie, teaching scenario design and duration of implementation) and the teaching performance outcome (ie, the performance of appropriate teaching acts) in VR training for student instructors. The impact of the two design variables has been murky in the literature. By using an ordinal logistic regression approach in this exploratory ex post facto study, we shed lights on this underexplored area.

Our results suggest that scenarios designed with different tasks and activities in VR can be conducive to desired performance outcome but with different odds, depending on the dynamicity for decision making in the interactive scenario designed. The six scenarios in our VR design differed in the odds to enact the student instructors for dynamic decision making and to exercise content and pedagogical knowledge. Compared to other scenarios, *DSK-PK scenarios* (ie, *Teaching Adaptively* and *Problem Solving*) require more dynamic decision making for teaching skills development. Participants who completed these two scenarios had higher odds of showcasing appropriate teaching acts, such as focusing on relevant questioning, monitoring students' performance, adjusting follow-up teaching acts in response to virtual students' comments or questions, and accurate content instruction. Differently, the content and tasks of *DSK scenarios* (ie, *Office Hour* and *Scientific Lab*) are predetermined and the target teaching acts tend to focus more on domain-specific knowledge practice instead of pedagogical knowledge. Notably, although student instructors can decide the topic to teach in the *Better Explanation* scenario, the prompts in *Better Explanation* are set to get student instructors to react with different ways of explanation for the same content/topic. For example, in explaining a topic in cybersecurity, the student instructor would draw different graphs on an interactive whiteboard for the same concept. This encourages less diversity of decision making and reasoning for pedagogical knowledge than in *Teaching Adaptively* and *Problem Solving* in which student instructors have to accommodate different learning needs. This finding contributes to the literature by specifying the scenarios that would train the student instructors for the specific outcome we focused on—dynamic decision making for teaching skills development that balances between domain-specific knowledge and pedagogical knowledge (Fowler, 2015).

Possible explanations would be that the student instructors could have more opportunities to engage in dynamic decision making in *DSK-PK scenarios* that foster diverse teaching practices. This result supports Fowler's (2015) *design for learning* approach stressing that task affordances contribute to part of the VR learning effectiveness. Specifically, to promote effective and desired learning outcomes, the key focus of using VR is the design of VR-supported teacher training activities and environmental features that leverage the unique affordances of VR. The task design should be well integrated with the interactivity in simulation-based teaching practices, thus enabling student instructors to balance and exercise teaching practices between content and pedagogical knowledge (cf. Shulman, 1986). We also noted that student instructors in our study tend to prioritize domain-specific content teaching and knowledge presentation in *DSK scenarios* (ie, *Better Explanation*, *Office Hour* and *Scientific lab*) whereas *DSK-PK scenarios* (ie, *Teaching Adaptively* and *Problem Solving*) enabled a balanced integration of content knowledge and pedagogical knowledge practices for student instructors.

A limitation observed by a previous study (Ke, Pachman, et al., 2020) is that the competition between physical space and design features/functionality in VR could lead to the lack of direct and intuitive manipulations of objects, reduction of interactivity, and hence less authentic, interactive micro teaching practice. The current study suggests that the VR interactivity could be enhanced by appropriate scenario designs (eg, a mix of *DSK-PK scenarios* and *DSK scenarios* in this study). Further, this study offered preliminary empirical evidence on the importance of integrating virtual agents in the VR teacher training environment. Virtual agents, as a role-playing partner to enhance social presence (Sinatra et al., 2021), can maintain a natural, open and supportive dynamicity with interactive prompts, questioning, and social cues in teacher training so that the student instructors are prompted and challenged to actively perform appropriate teaching acts. The practical values of virtual agents in teacher training were documented (Fukuda et al., 2018; Ke, Dai, et al., 2020). We further found that virtual agents in the *Teaching Adaptively* and *Problem Solving* scenarios prompted the student instructors to interact with students in a way that requires dynamic decision making in teaching.

Our results on duration of implementation in VR teacher training program indirectly support the notion that the learning tasks designed in our VR environment support teacher training. That is, engaging in one more session of VR-based training in this study will increase the possibility of demonstrating appropriate teaching acts significantly. The results highlight the benefits of a longer duration in VR-based teacher training and support the experiential learning theory (Kolb, 1984) in that *a constant duration* of involvement in transformative experience is critical for learning. This finding in VR environment also extends early instructional theory in school settings by suggesting that time is a critical factor for the effectiveness of learning (Carroll, 1963). We found that multimodal interactive features and information presentation in the current VR-based learning environment do not seem to impede learning as the time of participation extends (Freina & Ott, 2015; Makransky & Petersen, 2019). Aligning with Chernikova et al.'s (2020) meta-analytic findings, we found that the longer the duration of participation is, the more effective the training in VR will be. It also echoes the previous study finding that more proactive teaching acts are prone to be performed by the participants *later* in the training (Ke, Pachman, et al., 2020). It is suggested that stimuli from virtual students and environmental prompts could train participants to be more observant, autonomous, and attentive during VR-based teaching practice. This suggestion is in alignment with Ke, Pachman, et al.'s (2020) finding in that student instructors were more mindful after prolonged interactions with the virtual agents and environmental prompts. It should be noted that the current finding applies to desktop VR-supported simulation-based learning. Future research in immersive VR or mixed-reality environments is warranted to further examine whether extended time contributes to better learning outcomes and the ideal amount of time in relation to VR induced symptoms (eg, Sharples et al., 2008).

Taken together, our study findings suggested that knowledge construction and skills development in teaching are associated with scenario design and prolonged duration of participation in VR-supported simulation-based learning for teacher training. The stimuli from the virtual environmental and social features as well as greater degrees of interactivity in VR scenarios lubricate the learning process of teacher training by providing opportunities for the participants to enact dynamic decision making for teaching.

LIMITATIONS AND FUTURE DIRECTIONS

The current study has several limitations. First, although our results suggested a promising outcome—there were more *appropriate teaching act* (n = 2841) than *failed teaching attempt/ inappropriate teaching act* (n = 480), the proportionally uneven counts of the ordinal variable may be a concern for analyses. This is a similar limitation with Guimarães et al.'s (2010) research using ordinal logistic regression. Future research should confirm the findings of the current study with proportionally even distributed numbers of teaching acts or other research designs. Second, our assessment of the teaching performance is limited to one data source—based on the video-recorded behavioural analysis. Future studies should consider a more comprehensive performance assessment.

We also advocate that future research should further investigate the nuances or different training outcomes of different facets of scenario design as well as controlling or singling out immersive environmental design elements (Radianti et al., 2020). Disciplines of the student instructor is another potential future direction. It would be worthwhile to investigate unique teaching acts in relation to the scenario designed based on STEM disciplines. Finally, future studies should examine the affordances of different VR learning environments (eg, desktop VR, VR with HMDs, or mixed reality) and their effects on different learning outcome variables, such as self-efficacy or different teaching knowledge and skills. In this study, we adopted ex facto design using ordinal logistic regression with systematic video coding. This is a contribution to VR-supported simulation-based learning as Ledger et al.'s (2022) findings advocated for more quantitative research in this area. Aligning with Frei-Landau and Levin (2022), we also encourage more video analysis research to improve teacher education through an understanding of teaching acts.

CONCLUSION

To conclude, this study informs about the design and implementation of VR-based teacher training in higher education settings. To shed lights on the scenario design and the duration of implementation for VR-based teacher training, we explored the scenarios designed to promote DSK (Domain-Specific Knowledge) and the extended number of training sessions. The study indicates that VR-supported simulation-based learning environments for teacher training should be designed to enact the practice of dynamic decision making by the participants during learner-VR interactions and encourage them to exercise a balance between content and pedagogical knowledge (in DSK-PK scenarios). In addition, longer duration of participating in the VR-based training is associated with better teaching performance. These results support the usage of computer-based VR as a prominent platform for hosting the practice-based teacher training. Future research should continue exploring how to design scenarios that facilitate student instructors' balanced enactment of domain-specific knowledge and pedagogical knowledge.

ACKNOWLEDGEMENTS

This work was supported by the National Science Foundation, grant 1632965 and 2110777. Any opinions, findings and conclusions or recommendations expressed in these materials are those of the authors and do not necessarily reflect the views of the National Science Foundation.

CONFLICT OF INTEREST

The authors declare no conflict of interest in this study.

DATA AVAILABILITY STATEMENT

Being constrained by the human subject protection policies and the nature of the data, the original study data are not open. Anonymous analysis results are accessible upon reasonable request.

ETHICS STATEMENT

The study was conducted under the supervision of the university's Institutional Review Board. Ethical guidelines were followed.

REFERENCES

Agresti, A. (2002). *Categorical data analysis* (2nd ed.). John Wiley & Sons.

Araujo, S. E., Delaney, C. P., Seid, V. E., Imperiale, A. R., Bertoncini, A. B., Nahas, S. C., & Cecconello, I. (2014). Short-duration virtual reality simulation training positively impacts performance during laparoscopic colectomy in animal model: Results of a single-blinded randomized trial. *Surgical Endoscopy*, *28*(9), 2547–2554. https://doi.org/10.1007/s00464-014-3500-3

Bailenson, J. N., Yee, N., Blascovich, J., Beall, A. C., Lundblad, N., & Jin, M. (2008). The use of immersive virtual reality in the learning sciences: Digital transformations of teachers, students, and social context. *The Journal of the Learning Sciences*, *17*(1), 102–141. https://doi.org/10.1080/10508400701793141

Capraro, M. M., Capraro, R. M., & Helfeldt, J. (2010). Do differing types of field experiences make a difference in teacher candidates' perceived level of competence? *Teacher Education Quarterly*, *37*(1), 131–154. https://www.jstor.org/stable/23479302

Carroll, J. B. (1963). A model of school learning. *Teachers College Record*, *64*(8), 723–733.

Chernikova, O., Heitzmann, N., Stadler, M., Holzberger, D., Seidel, T., & Fischer, F. (2020). Simulation-based learning in higher education: A meta-analysis. *Review of Educational Research*, *90*(4), 499–541. https://doi.org/10.3102/0034654320933544

Cohen, J., Cohen, P., West, S., & Aiken, L. S. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed.). Lawrence Erlbaum Associates, Inc.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed.). Routledge.

Dai, C.-P., & Ke, F. (2022). Educational applications of artificial intelligence in simulation-based learning: A systematic mapping review. *Computers and Education: Artificial Intelligence*, *3*, 100087. https://doi.org/10.1016/j.caeai.2022.100087

Dai, Z., Ke, F., Dai, C.-P., Pachman, M., & Yuan, X. (2021). Role-play in virtual reality: A teaching training design case using OpenSimulator. In G. Akcayir & C. D. Epp (Eds.), *Designing, deploying, and evaluating virtual and augmented reality in education* (pp. 143–163). IGI Global. https://doi.org/10.4018/978-1-7998-5043-4.ch007

Dalgarno, B., Gregory, S., Reiners, T., & Knox, V. (2016). Practising teaching using virtual classroom role plays. *Australian Journal of Teacher Education*, *41*(1), 126–154. https://doi.org/10.14221/ajte.2016v41n1.8

Dalgarno, B., & Lee, M. J. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, *41*(1), 10–32. https://doi.org/10.1111/j.1467-8535.2009.01038.x

DeChenne, S. E., Enochs, L. G., & Needham, M. (2012). Science, technology, engineering, and mathematics graduate teaching assistants teaching self-efficacy. *Journal of the Scholarship of Teaching and Learning*, *12*(4), 102–123.

Dille, K. B., & Røkenes, F. M. (2021). Teachers' professional development in formal online communities: A scoping review. *Teaching and Teacher Education*, *105*, 103431. https://doi.org/10.1016/j.tate.2021.103431

Dubovi, I., Levy, S. T., & Dagan, E. (2017). Now I know how! The learning process of medication administration among nursing students with non-immersive desktop virtual reality simulation. *Computers & Education*, *113*, 16–27. https://doi.org/10.1016/j.compedu.2017.05.009

Ferdig, R. E. (2006). Assessing technologies for teaching and learning: Understanding the importance of technological pedagogical content knowledge. *British Journal of Educational Technology*, *37*(5), 749–760. https://doi.org/10.1111/j.1467-8535.2006.00559.x

Fowler, C. (2015). Virtual reality and learning: Where is the pedagogy? *British Journal of Educational Technology*, *46*(2), 412–422. https://doi.org/10.1111/bjet.12135

Frei-Landau, R., & Levin, O. (2022). The virtual Sim (HU) lation model: Conceptualization and implementation in the context of distant learning in teacher education. *Teaching and Teacher Education*, *117*, 103798. https://doi.org/10.1016/j.tate.2022.103798

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. In *The 11th International Conference eLearning and Software for Education—Rethinking Education by Leveraging the eLearning Pillar of the Digital Agenda for Europe* (Vol. 1, pp. 133–141). "Carol I" National Defence University Publishing House.

Fromm, J., Radianti, J., Wehking, C., Stieglitz, S., Majchrzak, T. A., & vom Brocke, J. (2021). More than experience? On the unique opportunities of virtual reality to afford a holistic experiential learning cycle. *The Internet and Higher Education*, *50*, 100804. https://doi.org/10.1016/j.iheduc.2021.100804

Fukuda, M., Huang, H. H., Kuwabara, K., & Nishida, T. (2018). Proposal of a multi-purpose and modular virtual classroom framework for teacher training. In *Proceedings of the 18th International Conference on Intelligent Virtual Agents* (pp. 355–356). https://doi.org/10.1145/3267851.3267917

Gibbons, A. S. (2020). What is instructional strategy? Seeking hidden dimensions. *Educational Technology Research and Development*, *68*(6), 2799–2815. https://doi.org/10.1007/s11423-020-09820-2

Goldberg, P., Schwerter, J., Seidel, T., Müller, K., & Stürmer, K. (2021). How does learners' behavior attract preservice teachers' attention during teaching? *Teaching and Teacher Education*, *97*, 1–14. https://doi.org/10.1016/j.tate.2020.103213

Guimarães, A. N., Silva-Mato, A., Miranda Cota, L. O., Siqueira, F. M., & Costa, F. O. (2010). Maternal periodontal disease and preterm or extreme preterm birth: An ordinal logistic regression analysis. *Journal of Periodontology*, *81*(3), 350–358. https://doi.org/10.1902/jop.2009.090527

Huang, Y., Richter, E., Kleickmann, T., Wiepke, A., & Richter, D. (2021). Classroom complexity affects student teachers' behavior in a VR classroom. *Computers & Education*, *163*, 1–15. https://doi.org/10.1016/j.compedu.2020.104100

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies*, *23*(4), 1515–1529. https://doi.org/10.1007/s10639-017-9676-0

Kayima, F., & Jakobsen, A. (2020). Exploring the situational adequacy of teacher questions in science classrooms. *Research in Science Education*, *50*(2), 437–467. https://doi.org/10.1007/s11165-018-9696-9

Ke, F., Dai, Z., Dai, C.-P., Pachman, M., Chaulagain, R., & Yuan, X. (2020). Designing virtual agents for simulation-based learning in virtual reality. In R. Zheng (Ed.), *Cognitive and affective perspectives on immersive technology in education* (pp. 151–170). IGI Global. https://doi.org/10.4018/978-1-7998-3250-8.ch008

Ke, F., Lee, S., & Xu, X. (2016). Teaching training in a mixed-reality integrated learning environment. *Computers in Human Behavior*, *62*, 212–220. https://doi.org/10.1016/j.chb.2016.03.094

Ke, F., Pachman, M., & Dai, Z. (2020). Investigating educational affordances of virtual reality for simulation-based teaching training with graduate teaching assistants. *Journal of Computing in Higher Education*, *32*(3), 607–627. https://doi.org/10.1007/s12528-020-09249-9

Ke, F., & Xu, X. (2020). Virtual reality simulation-based learning of teaching with alternative perspectives taking. *British Journal of Educational Technology*, *51*(6), 2544–2557. https://doi.org/10.1111/bjet.12936

Klingenberg, S., Jørgensen, M. L., Dandanell, G., Skriver, K., Mottelson, A., & Makransky, G. (2020). Investigating the effect of teaching as a generative learning strategy when learning through desktop and immersive VR: A media and methods experiment. *British Journal of Educational Technology*, *51*(6), 2115–2138. https://doi.org/10.1111/bjet.13029

Kolb, D. A. (1984). *Experiential learning experience as a source of learning and development*. Prentice Hall.

Korthagen, F. A. (2004). In search of the essence of a good teacher: Towards a more holistic approach in teacher education. *Teaching and Teacher Education*, *20*(1), 77–97. https://doi.org/10.1016/j.tate.2003.10.002

Kourtesis, P., Collina, S., Doumas, L. A., & MacPherson, S. E. (2019). Validation of the virtual reality neuroscience questionnaire: Maximum duration of immersive virtual reality sessions without the presence of pertinent adverse symptomatology. *Frontiers in Human Neuroscience*, *13*, 417. https://doi.org/10.3389/fnhum.2019.00417

Kuo, Y.-L., Casillas, A., Allen, J., & Robbins, S. (2021). The moderating effects of psychosocial factors on achievement gains: A longitudinal study. *Journal of Educational Psychology*, *113*(1), 138–156. https://doi.org/10.1037/edu0000471

Ledger, S., Burgess, M., Rappa, N., Power, B., Wong, K. W., Teo, T., & Hilliard, B. (2022). Simulation platforms in initial teacher education: Past practice informing future potentiality. *Computers & Education*, *178*, 104385. https://doi.org/10.1016/j.compedu.2021.104385

Liu, X. (2009). Ordinal regression analysis: Fitting the proportional odds model using Stata, SAS and SPSS. *Journal of Modern Applied Statistical Methods*, *8*(2), 632–645. https://doi.org/10.22237/jmasm/1257035340

Makransky, G., Andreasen, N. K., Baceviciute, S., & Mayer, R. E. (2021). Immersive virtual reality increases liking but not learning with a science simulation and generative learning strategies promote learning in immersive virtual reality. *Journal of Educational Psychology*, *113*(4), 719–735. https://doi.org/10.1037/edu0000473

Makransky, G., & Petersen, G. B. (2019). Investigating the process of learning with desktop virtual reality: A structural equation modeling approach. *Computers & Education*, *134*, 15–30. https://doi.org/10.1016/j.compedu.2019.02.002
Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education*, *70*, 29–40. https://doi.org/10.1016/j.compedu.2013.07.033
Moreno, R., & Mayer, R. (2007). Interactive multimodal learning environments. *Educational Psychology Review*, *19*(3), 309–326. https://doi.org/10.1007/s10648-007-9047-2
O'Connell, A. A., & Gray, D. L. (2011). Cause and event: Supporting casual claims through logistic models. *Educational Psychology Review*, *23*, 245–261. https://doi.org/10.1007/s10648-011-9158-7
Piaget, J. (1964). Cognitive development in children. *Journal of Research in Science Teaching*, *2*, 170–186.
Postareff, L., Lindblom-Ylänne, S., & Nevgi, A. (2007). The effect of pedagogical training on teaching in higher education. *Teaching and Teacher Education*, *23*(5), 557–571. https://doi.org/10.1016/j.tate.2006.11.013
Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, 1–29. https://doi.org/10.1016/j.compedu.2019.103778
Rau, M. A. (2017). Conditions for the effectiveness of multiple visual representations in enhancing STEM learning. *Educational Psychology Review*, *29*(4), 717–761. https://doi.org/10.1007/s10648-016-9365-3
Raut, P. (2018). *Analysis of immersive virtual reality vs. desktop 3D games* [Unpublished master's thesis]. Northeastern University.
Redfield, D. L., & Rousseau, E. W. (1981). A meta-analysis of experimental research on teacher questioning behavior. *Review of Educational Research*, *51*(2), 237–245. https://doi.org/10.3102/00346543051002237
Rienties, B., Brouwer, N., & Lygo-Baker, S. (2013). The effects of online professional development on higher education teachers' beliefs and intentions towards learning facilitation and technology. *Teaching and Teacher Education*, *29*, 122–131. https://doi.org/10.1016/j.tate.2012.09.002
Seidel, T., Schnitzler, K., Kosel, C., Stürmer, K., & Holzberger, D. (2020). Student characteristics in the eyes of teachers: Differences between novice and expert teachers in judgment accuracy, observed behavioral cues, and gaze. *Educational Psychology Review*, *33*, 69–89. https://doi.org/10.1007/s10648-020-09532-2
Sharples, S., Cobb, S., Moody, A., & Wilson, J. R. (2008). Virtual reality induced symptoms and effects (VRISE): Comparison of head mounted display (HMD), desktop and projection display systems. *Displays*, *29*(2), 58–69. https://doi.org/10.1016/j.displa.2007.09.005
Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14. https://doi.org/10.3102/0013189X015002004
Sinatra, A. M., Pollard, K. A., Files, B. T., Oiknine, A. H., Ericson, M., & Khooshabeh, P. (2021). Social fidelity in virtual agents: Impacts on presence and learning. *Computers in Human Behavior*, *114*, 106562. https://doi.org/10.1016/j.chb.2020.106562
Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments five: Speculations on the role of presence in virtual environments. *Presence: Teleoperators and Virtual Environments*, *6*(6), 603–616. https://doi.org/10.1162/pres.1997.6.6.603
Srivastava, P., Rimzhim, A., Vijay, P., Singh, S., & Chandra, S. (2019). Desktop VR is better than non-ambulatory HMD VR for spatial learning. *Frontiers in Robotics and AI*, *6*, 50. https://doi.org/10.3389/frobt.2019.00050
Steffe, L. P., & Gale, J. (Eds.). (1995). *Constructivism in education*. Erlbaum.
Suen, H. K., & Ary, D. (1989). *Analyzing quantitative behavioral observation data*. Lawrence Erlbaum Associates, Inc.
Van Driel, J. H., Verloop, N., & De Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching*, *35*(6), 673–695. https://doi.org/10.1002/(SICI)1098-2736(199808)35:6<673::AID-TEA5>3.0.CO;2-J
Wolff, C. E., Jarodzka, H., van den Bogert, N., & Boshuizen, H. P. (2016). Teacher vision: Expert and novice teachers' perception of problematic classroom management scenes. *Instructional Science*, *44*(3), 243–265. https://doi.org/10.1007/s11251-016-9367-z

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Dai, C.-P., Ke, F., Dai, Z., & Pachman, M. (2023). Improving teaching practices via virtual reality-supported simulation-based learning: Scenario design and the duration of implementation. *British Journal of Educational Technology*, *54*, 836–856. https://doi.org/10.1111/bjet.13296