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# Investigating educational affordances of virtual reality for simulation-based teaching training with graduate teaching assistants

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**Abstract**

This study investigated the affordances and constraints of a VR-based learning environment for the teaching training of university graduate teaching assistants in relation to the task, goal-based scenarios, and learning support design. Seventeen graduate teaching assistants participated in a multiple-case study with an OpenSimulator-supported, simulation-based teaching training program. The study indicated that the VR-based learning environment fostered participants' performance of interactive teaching and demonstrative instruction, while training them to notice and attend to students' actions/reactions during the instruction. On the other hand, there is a competition between physical reality and functional intelligence in the VR environment. We propose the integration of experience, affordance, and learner analyses in planning and designing a VR-supported learning intervention.

**Keywords** Virtual reality · Teaching training · Graduate teaching assistant · Simulation-based learning · Educational affordance analysis

## Introduction

Virtual reality (VR) has been implemented as a collaborative, highly interactive learning platform to support a variety of educational activities in both formal and informal learning settings (Hew and Cheung 2010; Merchant et al. 2014). In comparison with other computerized programs, VR supports in situ, simulated practice to enable the transfer of skills between taught and real contexts, and provides a multi-user and embodied space for real-time and multimodal interactions. A recent meta-analysis on virtual reality-based instruction in K-12 and higher education (Merchant et al. 2014) indicated that VR was effective in improving learning outcome gains

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(FEM = 0.36; REM = 0.41). Virtual reality is now considered a mature technology appropriate for pedagogical use (Mikropoulos and Natsis 2011).

On the other hand, current design and development efforts of VR-based learning are still driven by "common-sense extrapolations" rather than a solid, educational affordance analysis (Dalgarno and Lee 2010, p. 25; Mikropoulos and Natsis 2011). Educational affordances refer to "characteristics of an artifact that determine if and how a particular learning behavior could possibly be enacted within a given context" and whether the learning intentions of the user can be invited and supported (Kirschner 2002, p. 19). It is argued that for a VR-based learning environment, an educational affordance analysis should be conducted during the design and evaluation processes to match learning tasks, prompts, and supports with the functionalities of the VR technology as well as the learner characteristics (Bower 2008; Dalgarno and Lee 2010; Kirschner 2002). Yet empirical research investigating whether and how the functionalities and features of VR can be exploited in pedagogically sound ways is still lacking.

The current study is an in situ and empirical examination of the educational affordances supported by the salient features of VR in relation to the design of tasks, goal-based scenarios, and learning support. Specifically, we investigated the learning benefits and constraints of a VR simulation-based learning environment in the context of teaching training with university graduate teaching assistants (GTAs) from diverse academic disciplines.

## Theoretical perspectives

In this section, we review three frequently-mentioned, salient features of VR for learning in the literature. We then outline the prevalent modes or levels of teaching training experiences, especially for GTAs. Subsequently, prior research and findings on using VR-based teaching training are discussed.

### Salient features of virtual reality for learning

Burdea and Coiffet (2003) defined VR's nature as "Interaction-Immersion-Imagination." This description has pinpointed the three salient features of VR frequently discussed by prior conceptual reviews and design studies (e.g., Dickey 2005; Hew and Cheung 2010; Mikropoulos and Natsis 2011). It was believed that these features helped to facilitate experiential and contextualized learning while increasing learner motivation and engagement (Dalgarno and Lee 2010).

#### Interactivity of simulation

Interactivity of a simulation is defined as the degree to which the simulation *acts* like the real-world operational environment in reacting to the user actions or inputs (Hamstra et al. 2014). Prior research of simulation-based learning generally suggests that if the resemblance between the simulation and real-world operational setting captures the critical elements or properties of the skills/tasks to be taught, other aspects (e.g., physical and sensory resemblances) of the simulation could tolerate lower levels of realism or deviation from the real world without compromising training or learning effectiveness (Alexander et al. 2005). Actually, there is empirical evidence suggesting that an undue emphasis on physical resemblance can direct attention toward irrelevant aspects of the simulation platform and away from essential task elements central to the primary learning objective (Norman et al. 2012).

Interactivity or functional resemblance of a simulation is framed by: (1) the extent to which the simulated environment acknowledges the user's existence and reacts to it in the similar way as the real-world operational setting, and (2) interaction and social presence of multiple users in the simulated environment. In particular, cognitive interactivity—interactivity matched with the learning needs regarding the functional property and operation of the simulation system—is found one of the most effective instructional design features in simulation-based education (Cook et al. 2013; Hamstra et al. 2014).

### Immersion in VR-based learning

Immersion can be defined as quality of a simulation that affords mental absorption in a particular experience and/or a perceptual presence within a simulated space (McMahan 2013; Sherman and Craig 2003; Witmer et al. 2005). Immersion can be classified to two types: diegetic immersion that occurs when one becomes absorbed into the experience, and situated immersion that occur when one not only acts on but experiences the illusion of existing within the simulation through the character (Alexander et al. 2005; McMahan 2013; Taylor 2002). The diegetic immersion signifies a flow or cognitive engagement experience while situated immersion denotes presence—the psychological sense of being in the simulated place, whether it is a virtual, physical, or computer-mediated environment (Lee 2004; Slater and Sanchez-Vives 2016; Witmer et al. 2005).

It is reported that immersion increases engagement with the simulation, enhances procedure memorization, skills acquisition, and knowledge transfer by allowing multiple perspectives and situated performance, and hence is a salient facet to be examined for simulation-based learning (Buttussi and Chittaro 2017; Dede 2009; Ragan et al. 2010). Prior research suggests that the level of learner control over their avatar, the environmental manipulation/interactivity, the naturalness of social interactions, the plot or environmental narrative of the simulation, along with the visual or sensory illusion of reality or presence afforded by the medium, are salient design factors inducing immersion (Bulu 2012; Ryan 2001; Sadowski and Stanney 2002).

### Imagination afforded by multiple representations in an extensible VR world

Natural semantics—spatial representation and concrete visualization—of a potentially invisible phenomenon or a physically inaccessible object is a unique functionality of the VR that promotes knowledge construction (Mikropoulos and Natsis 2011). Instead of using symbols, the VR environment supports the spatial representation of an invisible concept (e.g., the electric field) as well as an impossible event (e.g., a historic occasion). The extensibility of the virtual reality also enables the user to perform ‘modding’ (Hedberg and Brudvik 2008) with the simulation of complex scenarios that cannot be experienced much in daily life, thus fostering expansion and concretization of imagination or vision. Embodiment of users (via avatars), multimodal interactions (by drawing on spatial and non-verbal cues), and three-dimensional representations in a VR-supported simulated environment foster a greater ‘sense of place’, and hence it is likely that learners will more easily identify with their avatar as they are involved in participatory simulation or role-play for learning (Dalgarno and Lee 2010, p. 22).

## Teaching training for graduate teaching assistants

Teaching competence is multifaceted, encompassing: (a) discipline-specific knowledge, (b) understanding and adaptive implementation of the principles of teaching, and (c) understanding of how people learn specific subject matter and are motivated to do so (Berliner 1988). Correspondingly, a teaching training experience for graduate teaching assistants (GTAs) should offer them an opportunity to conduct and review in-context teaching performance, and reflect on their teaching practices and epistemic beliefs to develop a fine degree of understanding. Cruickshank and Armaline (1986) summarized four levels of experience in teaching training: (a) concrete-real—infield and clinical experiences of student teaching; (b) concrete-modeled—simulated teaching experiences, such as role-playing, microteaching, and simulation; (c) vicarious—observations of others teaching live in classrooms or on tape, and (d) abstract—learning from lectures, case studies and discussions. Prevalent training programs for GTAs depict mainly introductory presentations on pedagogy and administrative orientations and have typically relied on only abstract instructional strategies—learning from lectures, video-based case studies, and discussions (Pentecost et al. 2012).

Teaching is also a complex problem-solving task that requires noticing and weighing many variables while adaptively implementing principles of instruction, communication, and content representation in a highly situated context. Rather than mechanically executing a preset sequence of instructional events, teaching involves dynamic and complex interpersonal interaction skills. Specifically, teachers learn to “*notice*” and *interpret* classroom interactions by making connections between specific events and general principles of teaching and learning, including the acts of attending to what students are doing/saying and identifying analogies or representations to use to best convey ideas (Van Es and Sherin 2002). Therefore, education in teaching should be context specific and situated in a variety of authentic instructional and interpersonal interaction problems. However, the opportunity for problem- or simulation-based training in instruction for GTAs is scarce. Also largely unexplored is the design and research effort related to integrating highly-interactive technologies into GTA teaching training. Prior research of video-based classroom “noticing” and interpretation focuses on vicarious or observational learning, and may fail to engage teaching trainees in dynamic interactions with a complex, developing teaching situation, thus not providing enactive, situated learning of classroom noticing and teaching.

### VR-based teaching training

Prior studies examining VR-based teaching training programs generally focused on preservice K-12 teacher education (Theelena et al. 2019). In the previous studies (e.g., Badilla Quintana and Fernández 2015; Badilla Quintana et al. 2017; Mahon et al. 2010; Muir et al. 2013; Nissim and Weissblueth 2017), teacher participants either performed VR-based participatory simulation by role-playing with peer avatars, or observed simulated teaching scenarios to identify and interpret what is noteworthy about a classroom situation. They found that the desktop VR-based learning environment enabled pre-service teachers to practice classroom management or content presentation in context, supported sense of immersion or presence in an authentic classroom experience, and posed motivating challenges to active teaching and learning. Still, the outcomes reported were generally teachers' perceived learning, awareness, or self-efficacy rather than their teaching task performance (Theelena et al. 2019). Importantly, in a study examining teaching training via virtual classroom role-plays, Dalgarno et al. (2016) reported peer avatars could overact or act the role of students in an unrealistic way, and suggested that an enhancement to the VR-based role-play environment is to have student roles simulated by the computer. They also argued that a VR-based teaching training environment in which a student teacher can practice teaching "in their own time without the need to coordinate with other student teachers" should be particularly valuable (p. 147).

A few recent studies started to involve GTAs in VR-based teaching practices. Ma et al. (2016) conducted an exploratory study on GTAs' perceptions of acting as student avatars for a group of preservice teachers in a VR teaching simulation. Okita et al. (2013) studied whether teaching with virtual peers in a VR environment would assist graduate students better understand biology content topics. Neither of these studies examined the affordances of VR as a teaching training tool for GTAs.

## Methods

This multiple-case study aims to address the following two research questions.

1. How will a VR learning environment afford or support simulation-based teaching practices?
2. What are the design characteristics that enhance the educational affordance of the VR learning environment as a simulation-based teaching training tool?

### VR learning environment for teaching training

Designed and delivered via OpenSimulator—an open source virtual environment platform, a virtual campus was designed to simulate an assortment of daily teaching


**Fig. 1** Screen capture of a lab teaching simulation

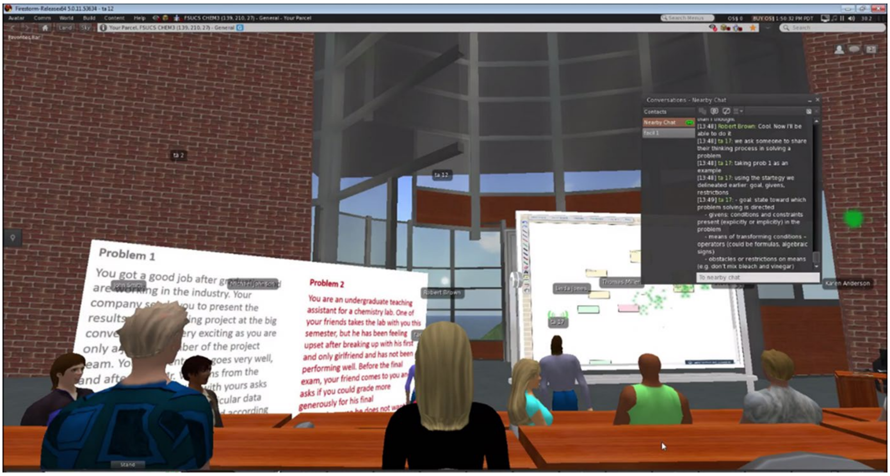


**Fig. 2** Screen capture of a class teaching simulation

scenarios and tasks for GTAs. These teaching simulations (see Figs. 1, 2, 3) contextualize, facilitate, and assess the practice of active teaching, such as teaching adaptively, explaining for better understanding, and facilitating scientific inquiry in labs. Each teaching simulation consists of three components: (a) a simulated teaching scenario that features a typical instructional setting (e.g., classroom or lab), a backdrop teaching task, and the associated teaching challenges (e.g., learner heterogeneity, difficult concepts, and lack of critical thinking); (b) interactive non-player characters (NPCs or virtual student agents) and/or facilitator-controlled avatars with whom GTA trainees will interact to complete the simulated teaching tasks; and (c) interactive information objects (e.g., virtual notecards and posters), lecture aids (e.g., a


**Fig. 3** Screen capture of a lab teaching simulation

virtual whiteboard and virtual scientific simulators), and dynamic scaffolds (e.g., via a pop-up dialogue panel) that scaffold teaching practices and foster the teaching knowledge development.

Based on prior research findings, the VR-based learning environment in the current study focused on stimulating active teaching practices by engaging participants in "*concrete-modeled*", microteaching experiences. We designed NPC students to present naturalistic prompting and feedback that aim to train participants to notice and interpret classroom interactions and identify effective ways to teach the subject matter. We embedded learning support or guidance in the VR environment as both interactive and background objects. Emphasizing functional resemblance, we designed cognitive interactivity of the VR environment using VR-compatible lecture aids (e.g., virtual whiteboard and simulator), simulated classroom arrangement (e.g., a physics or chemistry lab session), and scenario-specific virtual students whose inquiries or actions simulated typical challenges or behaviors in daily teaching settings.

## Participants, data collection, and analysis

Seventeen graduate teaching assistants were recruited from the disciplines of computer science (n = 5), chemistry (n = 3), physics (n = 5), biology (n = 1), psychology (n = 1), philosophy (n = 1) and modern language (n = 1). Among them, 6 were non-native English speakers, 11 were female, 3 experienced virtual reality before, and all had certain level (ranging from 0.5 to 3 years) of teaching experience.

All participants participated in an individual, 2-h VR-based teaching training session. Each participant with his/her teaching training session acted as a bounded case. Qualitative data were collected via screen and video recording, onsite observation, and end-of-session interviewing. Observation and interviewing were semi-structured, guided by open-ended prompts, such as "What is the participant doing (with

30 s as the unit of event recording)?" "How does the participant look?" and "What do you (the participant) think?"

We conducted both thematic and systematic behavior analyses with the screen captured participation behaviors during VR-based training. Thematic analysis consisted of: (a) open coding by which preliminary codes were attached to the observed data of each case, (b) cross-case comparative analysis that explored similar and different codes across cases, and (c) cross-case axial and selective coding that identified relationships among the cross-case codes to delineate core themes. The analysis contributed a set of thematic events and states defining the nature of learner-environment interactions and their VR-based teaching practices. Based on these themes along with their componential features and classifications, we developed a systematic coding protocol and conducted a behavior coding using BORIS (an event- or behavior-logging software). Two trained coders coded all participants' data based on the coding protocol, with the interrater reliability being .88 and all discrepancies then discussed and resolved. The frequency, average duration, and percentage of the salient VR-based teaching practices and learning interactions were then extracted from the systematic behavior coding (Fig. 4).

A cross-case thematic analysis was also conducted with the onsite observation and end-of-session interviewing data. This analysis focused on identifying salient actions and reactions of the participants toward the VR-based training tasks and prompts, as well as substantive statements encapsulating different participants' explanations and perceptions of their VR-based learning experience. The triangulation of the behavior coding, infield observation, and interviewing data enabled us to identify salient patterns governing the affordances and supportive design features of a VR-based learning environment as a teaching training tool.

## Results

### VR-simulation enacted teaching practices

The behavior analysis results indicated that the designed VR simulations enacted participants' teaching practices. On average, approximately 54.1% of the participants' involvement (or 64.25 min, in 17.33 events) in the VR space was contributed

| | Behavior type | Key | Code | Description |
|---|---|---|---|---|
| 1 | State event | a | Attending to students | Teaching practice: Paying attention to students and accomodating their needs |
| 2 | State event | c | Communication | Communicating with the facilitator, including social communication and negation about teaching topics |
| 3 | State event | e | Exploration | Exploring the virtual environments |
| 4 | State event | g | Instructional Guidance | Scaffolding delivered by environment, including blue dialogue boxes, notecards, videos, posters |
| 5 | State event | i | Interacting with students | Teaching practice: interacting with NPC students during teaching, including directly answering questions, prompting, delegating, and facilitating |
| 6 | State event | t | Interactive training | Interactive training activities that trainee may participate with peers |
| 7 | State event | l | Lecturing | Teaching practice: giving a lecture |
| 8 | State event | s | Scaffolding | Facilitator delivered scaffolding |
| 9 | State event | u | Using VR-enabled instructional tools | Teaching practice: using VR-enabled instructional tools, including concept map, simulators, interactive whiteboard |
| 10 | State event | v | Virtual field of view | Observable area in the virtual world seen on viewer screen |

**Fig. 4** Part of the coding protocol

to VR-based teaching practices. More than 60% of the participants engaged in mostly simulation-based teaching practices (with 60% + of their participation) during the training session. These teaching practices included the acts of interacting with students (21.18%), lecturing (being 17.98% on average), applying VR-based lecture tools (17.29%), and attending to students (1.53%). The next highest-percentage involvement of the participants (being 35.26% on average) was interacting with scenario-situated cuing or guidance (such as responding to on-screen prompts, reading virtual notecards and posters, or watching embedded videos) amid a teaching task, suggesting an active processing of the performance scaffolds by the participants.

Participants were found to practice mainly interactive teaching in the VR space, as fostered by intermittent prompting by NPC students, the presence of interactive lecturing tools, and task-relevant cuing in the VR space. The processes of lecturing, responding to students' inquiries, and applying the instructional tools to explain the subject matter were frequently interleaved. On the other hand, the lack of lively, reciprocal interactions with NPC students and the novelty of VR lecture tools reduced the functionality of VR teaching simulation and created demand for learner agency in imagination. The increase of multimodal cuing and distributed prompting in the VR space appeared to demand a participant's capability of cognitive sets-shifting—shifting attention and action between tasks or representations based on the situational demands. However, not all participants managed to attend to or process subtle contextual changes in the simulated teaching scenarios. Details on these identified patterns, supported by the observation notes and participant quotes, are reported below.

## Interactive teaching with NPC students

None of the participants questioned the authenticity of the computerized students, thinking those were human-controlled avatars. Almost all participants were found appropriately addressing NPC students' inquiries, with each participant engaged in averagely 8.73 events of interacting with students during the teaching-training session. Some participants adjusted their way of instruction to students' prompts, as the follow examples illustrated.

> CS-GTA4 (during the task of "explaining for better understanding") was proactive with student interactions, trying to approach students before they raised future questions. One of students' request ("what would be a metaphor of…") prompted him to think about alternative ways to explaining a concept, "Ah, I can't really think of one right now. Um…I got put on spot (smiling)." He pondered a minute, then read a cue on the metaphor usage from the pop-up dialogue panel, and came up with the response, "You think of 'the pointer' as address of the house…that points to a house". He then described the address of 'variables' as how the students are seated or positioned in a class, "So Karen sits at the first row, on the first seat. She has her position in classroom and that's what we call the address." Later during the interview, he expressed his appreciation of the metaphor group activity (i.e., letting student groups creating metaphors for a concept

and selecting the best metaphor with a justification), “I have never thought about using a group game in a programming class.”

CS-GTA5 (during the task of “teaching adaptively”) appeared patient towards the NPC students who intermittently interrupted her lecturing with questions on either the content topic or the class requirement. She responded affirmatively:

“You don’t understand my example? Ok, let me explain a little bit further.”

“Why do you need the ‘cache’? That’s a great question! The cache will be sitting in between the memory and the processer. The memory is too big for us, so something in between will…”

“Yes, we do have handouts and they are the course website. So you can just go and look at them, we posted them on Canvas (course site).”

P-GTA3 (during a “physics lab” task) appeared excited about the presence of a student-filled lab, “Oh, interesting!” She made an introductory lecturing on the lab content using the scientific simulator in the VR space, then walked around the lab to help students with their lab assignment. Notably, she followed the cue (from a pop-up dialogue panel) to scaffold scientific inquiry rather than giving answers to the students. For example, she mentored one student who reported on a broken ohmmeter, “Well, let’s check your setup. You have your ohmmeter positioned correctly to measure a total current, so…why do you think it’s broken?” A moment later, she thought aloud, “I think I should say something specific.” She then went back to the student and asked, “Why did you connect your voltmeter to…? What do you think?”

These observation notes suggested an interactive, student-oriented manner of teaching by the participants, possibly stimulated by NPC students’ prompts amid the instruction. Their explanations and responses were rich with specifics of the subject matter, indicating perceived authenticity with NPC students. Moreover, they mindfully consulted the environmental support—task-relevant cuing by the pop-up dialogue panel—during teaching practices. When interviewed, participants generally expressed their appreciation of the opportunity to learn how to “answer questions from the students that are kinda hard.”

On the other hand, multiple participants reported that their interactions with NPC students were not sufficiently reciprocal when they sought follow-up feedback. They also deemed it confining or unnatural to only use text-chat with NPC students, as portrayed in the following examples.

CS-GTA1 (during the task of “teaching adaptively”) appeared enthusiastic with her virtual students, “Oh, look at those students! Hi, students (laughing)!” She tried to involve her students during the instruction, “Let’s make cat a c-string. Who likes cats? Does anybody likes cats?” She waited for a response from NPC students to this inadvertent initiation and was disappointed with their silence, “Shame. I like cats.” On one occasion she kept waiting for a student response until the facilitator explained that those students weren’t able to participate in a spontaneous conversation. She finally realized that those NPC students were not human controlled. In spite of this recognition, she continued prompting her virtual students in a personal and imaginative manner, such as “Robert, you were

> paying attention during the last class, what's a C-string?" "Give me the other word that we would use in double quotes and it will give you your string…anyone?" "Ok, so what are the points you missed, Karen? I can go over it again."
> CS-GTA3 (during the task of "teaching adaptively") initially was so concentrated on his lecturing via the interactive whiteboard that he kept ignoring student inquiries sent via the text-chat. When he was cued to check the text-chat, he commented, "Oh, so I need to look at this chat because there is no voice."
> Ch-GTA1&2 (during a "chemistry lab" task) were responsive to NPCs' inquiries and comments. But they never approached the students who they were interacting with; neither did they adjust the VR viewer to check on their students during text chat.

As illustrated above, a participant was trying to present a personalized, interactive lecturing but her presentation was somewhat dampened by the limited functionality of NPC students (in maintaining a live dialogue). She had to maintain the interactive teaching flow with imaginative play (e.g., by faking a response from the students). The examples also indicated that the text-chat prompt could be ignored in the VR space. And when the participants got used to text-chat-only interactions, they became less attentive toward multimodal, environmental cues or prompts.

### Demonstrative instruction by using interactive VR lecture aids

Using VR lecture aids, such as virtual whiteboards and interactive simulators, was frequently observed among the participants and occupied 24.72% and 13.29% of the training session respectively. Participants' usage of a lecture aid (e.g., the interactive whiteboard versus the simulator) was related to the teaching task at hand. They used the interactive whiteboard to present visualized information or conceptual explanation during the class-teaching task (occupying averagely 22.89% of the training session). During the lab-teaching task, they used the virtual simulator (averagely 12.87% of the session) more than the interactive whiteboard (averagely 4.73%), typically to "show students the procedures of the lab". Three GTAs who were less versed in technology chose not to use the simulator during the virtual lecturing, while a few other GTAs complained that the font size on the virtual whiteboard was "too small" and ended up using the simulator. Either way, all participants were found demonstrating a descriptive or demonstrative manner of teaching by using the interactive lecture aids in the VR space. Their demonstrative teaching with the VR lecture aids was illustrated in the following observation notes.

> Participants (during a "physics-lab" task) frequently used both virtual whiteboard and the simulator when giving the lab intro. For example, one drew the diagrams of series and parallel circuits on the virtual whiteboard to explain concepts, "So our first example will be a diagram (pointing at the diagram on the whiteboard)… If we had 2 resistors connecting in parallel (drawing on the whiteboard)…they will look like this. Now, the end of this resistor is connected to the other side of the other resistor." Free drawing on the whiteboard enabled a metaphorical expla-

nation, "If you have your first resistor here and all the arms from one side will be there together—as two of the friends holding hands."

She then used the virtual simulator of ohmmeter to demonstrate the dynamics governing the circuits and explain the experiment procedure by interacting with the simulator, "So take this dial and put it as ohmmeter, now I gonna measure resistances of these resistors (conducting the described manipulation) …so it's 0.49" (Fig. 5)

Participants (during the class-teaching task) actively used the virtual whiteboard to explain formula and symbols and offered a pictorial description of the concepts. They drew and wrote when they were explaining the concepts, giving examples, and answering questions from NPC students:

"So, the first thing we are talking about are c strings. Does anyone remember arrays from last class? So what it's gonna do – it's gonna store a c string like this (drawing) 'c a t'. And then it's gonna have a null terminator.""That's what we gonna draw right now: on top you have a processor, so it's just a square and this thing has registers in it, so let's just add some text…Now, let's have a quick review on what we know about cache. Who can tell me what you know about cache?"

In the above examples, the virtual whiteboard and simulator enabled pictorial representations of concepts and procedures for teaching. The whiteboard was preferred when verbal expression and free-drawing were prioritized, whereas the interactive simulator helped to demonstrate the dynamic processes of a complex concept or procedure. Some GTAs also used virtual posters during lecturing, yet none of them used or requested for a PowerPoint presentation via the VR media-board.

A disadvantage of virtual lecturing, as reported by the participants during interviewing, was that they had to explore alternative ways, such as verbal and explicit

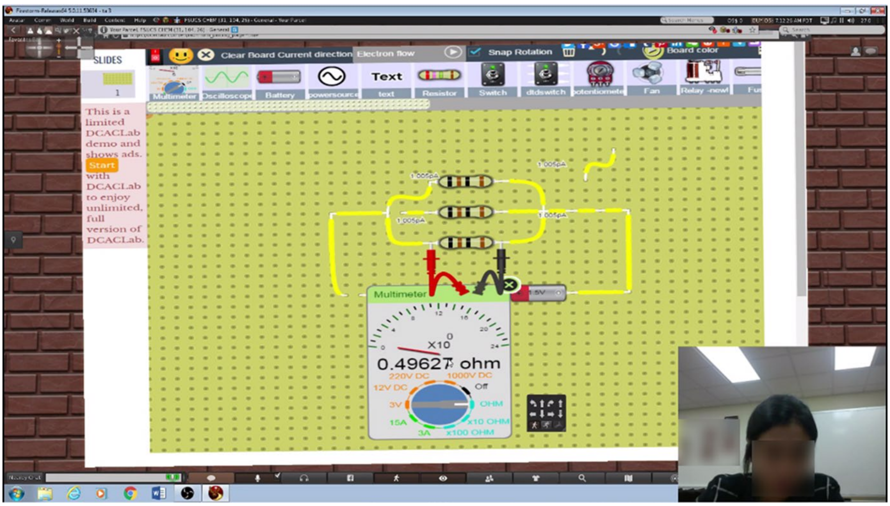


**Fig. 5** An example of the simulator usage during lecturing

questioning, to check for student understanding since virtual eye contact was not supported in the VR. Checking on individual students' non-verbal expressions during lecturing in the VR space required purposeful efforts (e.g., habitually adjusting points of view among the lecture aids and students). On the other hand, it trained the participants to consciously practice the teaching action of "noticing"—learning to identify what is noteworthy about a particular class situation (Van Es and Sherin 2002).

### Noticing and interpreting classroom interactions

Replicating the real-world teaching situation, NPC students' actions and reactions along with background animations in the virtual classroom (e.g., managing fire emergency in a chemistry lab) worked as naturalistic stimuli and feedback for the participants' teaching practices. These naturalistic and environmental prompts, as observed and self-reported, fostered authenticity of the VR teaching simulation. However, they failed to fully capture the participants' attention in a 3D environment. An NPC student's nonverbal gesturing, especially when the expression was delicate, was intermittently ignored by the participants. The behavior analysis indicated that less than 5% of the participation actions were indicative of a *proactive manner* of attending to students (e.g., facing students, walking around or approaching students, or zooming in to check on students).

Prominently, all proactive acts of noticing and interpreting classroom interactions occurred during the latter part of the training session. It appeared that participants became more attentive and observant after continuously reacting to NPC students' and environmental prompts. Approximately half of the participants learned to patrol the classroom or approach individual students when they posed a question. However, not all participants showed confidence or ease in maneuvering their avatars to move around in the VR space, which may have reduced their involvement in monitoring the virtual classroom. Interestingly, some participants chose to identify and stay at a fixed spot in the virtual classroom where they could easily see the whole scene or shift views between the lecture aids and the students. Such a spot was identified by the participants as their virtual "teaching stand."

## Design characteristics for VR-based teaching training

By examining the participants' involvement in teaching or non-teaching related activities in relation to the contextual and learner characteristics, we found the following design characteristics fostering the educational affordances of VR for simulation-based teaching training: (a) context-sensitive, coherent support before, during, and after a teaching task; (b) adaptive virtual points of view that fosters multi-way interactions with characters and lecture aids during a virtual instruction; (c) VR learner preparation; and (d) design of VR-compatible learning actions. These characteristics illustrated the relationships between the innate properties of VR, features of VR-compatible learning activities, and learner characteristics underlying the active and reflective practice and learning of teaching.

### Context-sensitive and coherent task support

In the current VR-based teaching simulation, task-relevant learning support was delivered via a pop-up dialogue panel during and instantly after a task, whereas generic guidance was presented via notecards before the task. We found that the in situ, task-related scaffolds fostered participants' teaching task performance, as the following observation and interviewing quote portrayed.

> After reading a pop-up cue on using metaphor in explanation, CS-GTA2 talked to his virtual students, "Since today's class is more about UNIX programming language. I'm trying to simplify things by making a connection between something that you already know and you are familiar within this environment."
> "Those (cues) were good. Those were actually helpful. If I was stuck, I would look up there."

On the other hand, the during-task support might be overlooked by the participants when the demand of interactive teaching increased or when they were multitasking (e.g., maneuvering a lecture aid while checking on students' reactions). The behavior analysis results indicated that participants spent 16.32% of the session operating or processing the pop-up cues during a class-teaching task). In comparison, during a lab-teaching task the participants spent only 9.85% processing the cues of the dialogue panel while 14.41% ignoring it during the session (e.g., leaving the pop-up dialogue panel open without interacting with it). Besides, all participants were found reading the notecards before their teaching actions. All participants actively typed their responses to the reflection prompts via the dialogue panel (e.g., "what are the ways to monitor student progress with their lab experiment?") after a teaching action. Their task-support usage occurred typically before and after a task, or in between teaching actions (e.g., from a lab introduction to the lab facilitation). The support usage quickly ebbed during a teaching action.

There was a trend of positive correlation between the act of using the task-support features and the act of attending to students, Pearson's $r = .55$, $p = .08$. On the other hand, the correlation between the usage of task supports and the acts of lecturing or interacting with students was non-significant, $p > .1$. These findings supported the interpretation that the during-task guidance could be interruptive to an interactive teaching action (e.g., lecturing and interacting with students). An implication is that the timing and content of the learning support needs to be aligned with the activity context to be perceived as assistive and nonintrusive.

### Adaptive virtual points of view for teaching interactions

An innate advantage and disadvantage of a desktop-supported virtual reality, in comparison with a real world, is the capability of and the demand for adjusting alternative perspectives (i.e., shifting between exocentric and egocentric perspectives) and fields of view (i.e., zooming out and in). The act of adjusting virtual points of view (POV) accounted for an average of 15.86% of the participants' involvement in a teaching task. There was a significant association between the act of virtual POV adjustment and the engagement of teaching practices, Pearson's $r = .70$, $p = .01$. Particularly, the act of virtual POV adjustment was significantly correlated with the act of using VR-embedded learning-support features, Pearson's $r = .72$, $p < .01$. The participants typically adjusted POV to enable multi-way interactions with NPC students, the lecture aids, and task-support features. As illustrated by the following examples, the POV adjustment encouraged a purposeful practice of teaching management, but posed a learning curve for novice participants.

> CS-GTA5 stood by the whiteboard while lecturing (see Fig. 6). She constantly adjusted POVs—camera adjustments and zooming—when lecturing and answering students' questions, and did it all the way through the task till when she was supposed to discuss the quiz results. The same pattern was observed in multiple other participants.
> CS-GTA1 originally chose to stand behind where the students were seated while delivering the lecture, "I gonna stand behind you, students, so you'd better be on your best behavior" (laughing). By doing so she didn't need to do much POV adjustment when operating the virtual whiteboard. Later she realized that she was missing some nonverbal expressions of students and then moved to the right side of the whiteboard where she had to shift POV regularly to attend to both the whiteboard and students.

## Well-versed VR learner preparation

The VR-based simulations, due to the presence of multiple dynamic objects and multimodal signals or communications, could be overwhelming to novice users. The participants spent a considerable portion of the session (17.55% by average) on environmental exploration. There was a significant, negative association between the

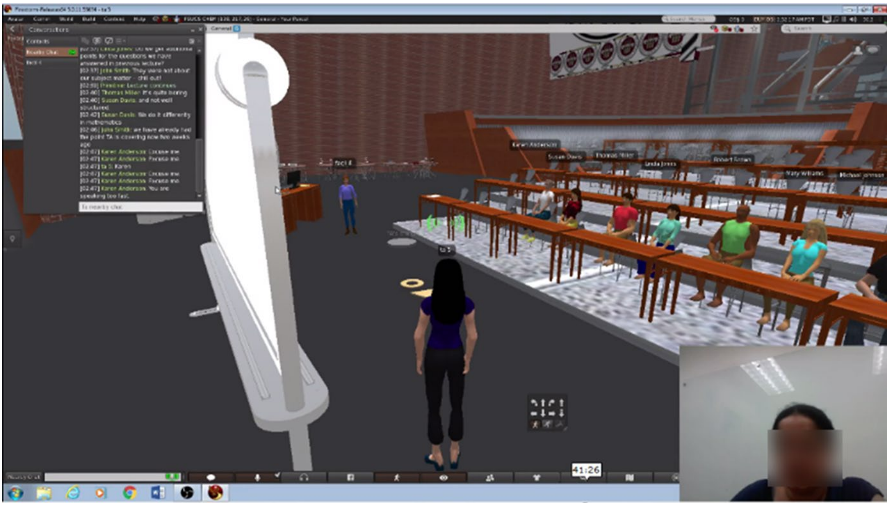

**Fig. 6** An example of virtual lecturing beside the whiteboard

engagement in environment exploration and that in the targeted teaching practices, Pearson's $r = -.60$, $p = .04$. The more one was involved in exploring or learning the VR environment, the less he/she was engaged in the teaching practice or learning.

On the other hand, it was observed that participants' performance of interactive teaching and demonstrative instruction was frequently associated with an adept interaction with the VR teaching tools and environment. Participants differed in their agency and efficiency in learning, experimenting with, and adapting to the VR teaching environment and objects. Two participants who did not spent sufficient time exploring the VR space tended to skip using the VR lecture aids, and hence failed to enact demonstrative instruction. They also showed reluctance to patrol the classroom or proactively interact with their virtual students, thus not fully leveraging the interactivity of the VR-based teaching simulation. During interviewing, participants suggested the integration of a set of pre-training tasks in the VR simulation to prepare users as well-versed VR learners. Similar to the "training arena" in a game, it was suggested that the embedded learner-preparation tasks should train novice users on the desirable, VR simulation-based learning skills (e.g., agency in experimenting with a novel teaching technique or tool).

### VR-compatible learning actions

During VR-based teaching training, the principal learning action involved by the participants was participatory simulation-based microteaching that was augmented by student agent-delivered naturalistic feedback as well as in situ, head-up displayed task-performance support. As reported above, participants also attended to and processed direct instructions that were presented via the VR notecards before each teaching task. They then engaged in reflection at the end of each teaching action through written responses to the pop-up, interactive prompts. As reported in the previous section on VR simulation-enacted teaching practices, the participants generally performed and engaged in all these targeted learning actions. The behavior analysis and interviewing results confirmed that these designated learning actions were compatible with the innate features of the VR platform to support an active and reflective learning experience.

## Discussion

The study findings indicated that the VR-based learning environment fosters participants' performance of interactive teaching and demonstrative instruction, and trains them to notice and attend to students' actions/reactions during the instruction. There is evidence suggesting that the participants manage to process and leverage the environment-situated learning support during their teaching events, thus demonstrating a better understanding or application of the embedded teaching knowledge. These findings, consistent with prior research report (e.g., Theelena et al. 2019; Nissim and Weissblueth 2017), supported the educational affordances of the VR environment for training active teaching. This study also provided initial evidence supporting the usage of non-player student agents in an open-source VR environment, which enables a future instructor to practice and learn teaching in their own time and without the need to coordinate with peers or other users (Dalgarno et al. 2016).

On the other hand, participants' interaction with the performance support deteriorates with the increase of multi-way interactions and multiple graphical presentations in the VR environment. The study findings suggested that VR interactive prompts for situated or reflective learning should be context-sensitive in its timing and semantically relevant to the operation or event at hand, otherwise it could be perceived as interfering rather than value-added.

The lack of reciprocal interactions with NPC students reduces the cognitive interactivity of the VR simulation, posing a demand on the participants' agency in imagination during simulated teaching scenarios. The novelty of the virtual lecture aids composes a learning curve for novices and reduces the easiness of virtual lecturing. The capability of adjusting points of view, such as taking alternative first- and third-person perspectives, may have supported the participants' reflective observation of their own teaching performance while promoting their mindfulness in noticing and gauging diverse classroom events and objects (to the extent that they would identify a virtual "teaching stand" for interactive teaching). Nevertheless, it reduces the functional resemblance of the VR-based teaching environment for the participants to frequently and consciously align points of view with varied objects of attention during interactions.

Based on the above study findings, we want to highlight a functional constraint of the current VR environment and the potential strategies or directions for the future design and implementation efforts. We also propose that future research should integrate the analyses of learning experience, environmental affordance, and learner characteristics in planning and designing a VR-supported learning program.

## Competition between physical reality and functional intelligence in the VR environment

Despite the recent development of virtual environment toolkits, the potential of adding intelligence to virtual agents (or NPC students) is still limited by the need to respect the real-time processing constraints of the VR and "the bias" of current available virtual environment platforms "towards visual realism and the graphical support of the VE rather than towards the addition of intelligence" (Luck and Aylett 2000). On one hand, efforts are made to sustain the physical reality that is important to the feeling of presence for the VR user; on the other, it is difficult for the designers to develop and implant multiple intelligent virtual agents (or students) that can *sense* the presence or approaching of a teacher avatar, *face* back toward the teacher, *process* the verbal protocols of the teacher, *respond* with or *portray* classified and varied actions. All those intelligent agent behaviors are constrained by the processing power of the current VR systems, thus reducing the functional resemblance or authenticity of NPC students in the VR space as the current study indicated.

A potential design strategy to increasing functional interactions with virtual agents is to design a choice-based interaction interface that enables the user to interact with virtual agents through semi-structured (e.g., multiple-choice) responses during a simulated scenario, thus reducing the need for text or nonverbal action processing. Another way to increase the functionality of student agents is to develop a high-level NPC description (or design) language along with a VR software toolkit. They can describe and generate a variety of scenario-specific NPCs that simulate a representative set of student archetypes and their learning states, by portraying categorized actions and responses. The selection and activation of specific actions or responses can be event-triggered through a real-time data mining of the user avatar's virtual activities captured by VR activity logs.

Another result of the innate competition between the physical and functional reality in VR is the lack of maneuverability or complex interactions between the users and VR objects. In this study, we have tried to leverage the current salient VR features, such as notecards, head-up display, media boards, and script-embedding objects, as the knowledge objects. However, interactions with these objects are still limited. For example, it is hard to dynamically increase or reduce the font size or create a dynamic visual display in a VR notecard or a head-up display. The loading of highly interactive simulation in a media-board can be jerky due to the processing and Internet speed constraints. Future design and research on how to develop a VR learning environment that enables complex properties of knowledge objects are warranted.

## Experience, affordance, and learner analyses for VR-based learning

This study suggested that a VR-based learning environment will convey a simulation-based, highly interactive experiences that frame active representation, application, observation, and reflection of the target competency. A proactive design analysis of the learning experience to be conveyed is therefore obliging. Based on the current study findings, principal design facets of the VR experience should include: the primary learning action (e.g., spontaneous or prompted role-playing, observing and identifying, exploring and reflection), the mode of action (e.g., individual or collaborative), the tools and/or rules of the action (e.g., aids for virtual lecturing), objects and agents to interact with during the action, an environmental narrative that frames the task or mission (e.g., a classroom scene with background objects), and environment-situated learner support.

The design analysis of the VR-based learning experience should be allied with an analysis of functionalities afforded by and the constraints of the current VR platform, as well as an analysis of the learner characteristics and intentions. For example, in this study the VR-based learning has prioritized GTAs' need to receive training in their own time. Hence the design and analysis focuses on concrete-modeled teaching interactions between the GTAs, NPC students, and task-relevant teaching tools and supports. A future design of VR-based teaching training in a synchronous group training, differently, could investigate a mixture of NPC characters and player-controlled avatars for teaching-related role-play. In this study the users were voluntary participants, motivated about teaching, and mindful in enacting role-play and processing cues and reflective prompts embedded in the VR environment. Given a different learner group (e.g., GTAs who consider teaching training only as an add-on to graduate education, or prefer vicarious learning), future VR-based learning researchers or designers should consider and examine alternative types and modes of learning action (e.g., a group observation and analysis of VR teaching simulation) or employ more stimuli or incentives for situated learning supports (e.g., audio prompts and rewards for support usage).

Overall, this study supports the previous finding (Theelena et al. 2019) that the desktop VR-based learning environment enables future instructors to practice teaching in context and provides a concrete-modeled teaching-training experience. The findings attest to the argument that design and research exploiting educational affordances of VR—an integrative analysis of learning experiences, learner characteristics, and technological features—is important (Dalgarno and Lee 2010). Particularly, future research should examine efficient design solutions that focus on enhancing functional resemblance or cognitive interactivity of a VR simulation for learning purposes.

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