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Designing Learning Support for Simulation-Based Preservice Teacher Learning with Artificial Intelligence-Powered Virtual Agents

Chih-Pu DAI
University of Hawai'i at Mānoa, USA
cdai@hawaii.edu

In this study, I explored how preservice teachers interact with learning support designed for situational pedagogical practices in virtual reality-supported simulation-based learning with artificial intelligence (AI)-powered virtual student agents. The learning support was designed and integrated into an existing simulation-based learning environment. Using a case study approach, I collected data from multiple sources for triangulation and credibility. Nineteen preservice teachers participated in this study. Three major themes endorsed the design and implementation of in-situ learning support and AI-powered virtual students in the virtual reality simulation for preservice teachers——1) collective reasoning with AI-powered virtual students that builds productive discourse, 2) intentional practice to probe and inquire AI-powered virtual students' scientific reasoning, 3) analyzing developmentally-aligned AI-powered virtual students' discourse in-situ. Future research should consider providing adaptive in-situ learning support to preservice teachers by gauging preservice teachers' situational pedagogical practices using natural language processing and machine learning algorithms.

Keywords: Artificial intelligence, learning support, simulation-based learning, teacher education, virtual reality

Introduction

Effective cultivation of students' learning in essential critical thinking and problem-solving skills within science disciplines relies on teachers employing intentional pedagogical practices, as well as possessing the necessary knowledge and skills to facilitate inquiry-based classroom discourse (Kraft & Hill, 2020; Schleicher, 2012). Improving preservice teachers' knowledge and skills requires authentic opportunities for "relational practice" (Grossman et al., 2009, p. 2057). Relational practice prepares preservice teachers to build teaching skills that strive for student-centered pedagogy. There are some commonly used activities in teacher education for relational practice, for example, role-play, workshops, and written case analysis (Grossman et al., 2009; Kaufman & Ireland, 2016). One of the primary goals in preparing preservice teachers for relational practice is to enable preservice teachers to actively embrace a teaching approach that not only acknowledges and values students' thinking processes, but also involves the thoughtful analysis of students' reasoning and resources they brought to the classroom discussion. As a result, the classroom interactions and discourse can facilitate productive discussions and nurture students' thinking. In doing so, students can be prepared for more advanced scientific reasoning (Kraft & Hill, 2020; Schleicher, 2012).

In the context of classroom teaching practicum, preservice teachers gain essential teaching competencies through clinical, hands-on practice, and deliberate reflection on their interactions with the students. However, these practicum opportunities are not only laden with high-stakes but also resource-intensive. When preservice teachers engage in real classroom teaching settings, there is a limited chance to improve the practice by resetting or repeating the interactions, under which circumstances the impacts of the interactions on students are substantial. Additionally, it requires significant resources for teacher educators to identify suitable classrooms and students for these teaching practicum experiences. Specifically, authentic classroom teaching experience and students' interactions often involve dynamic pedagogical reasoning and *in-the moment* decision making for the preservice teachers (Dai, 2023; Gibbons et al., 2021; Kavanagh et al., 2020); this type of clinical experience often requires intensive practices and reflections. Therefore, addressing the challenges of delivering high-fidelity simulations of classroom settings and student interactions to adequately prepare preservice teachers and provide more practicing opportunities before they enter to the authentic classrooms emerges as critical and imperative (e.g., Darling-Hammond, 2000).

Virtual reality (VR) simulation has shown promising potential in education and teacher learning (e.g., Dai, 2023; Liaw et al., 2023). As a type of 3-dimensional multimedia environment, VR simulation affords inquiry-based opportunities for learners to explore and practice knowledge and skills (Dai et al., 2023; Grossman et al., 2009). The integration of VR and artificial intelligence (AI), in the form of virtual agents in simulation-based learning, brings promising possibilities to address issues in different disciplines, including in education (Luck & Aylett, 2000). Using AI-powered virtual agents to provide real-time interactions for preservice teachers to practice teaching is one example (e.g., Dai & Ke, 2022). During the *inquiry-based learning process*, learners may struggle with the necessary dilemma or quandary contributing to their learning. To address these challenges, adding learning support in such contexts is one way to maximize the potential for simulation-based preservice teacher learning with AI-powered virtual agents. However, the research on using learning support when preservice teachers are practicing teaching in VR learning environments is limited. This study investigates *in-situ* reflective learning support aimed at enhancing the inquiry-based learning process *during* simulation experiences.

The purpose of the current study is to explore the phenomenon of the interactions between learning support and preservice teachers in simulation-based learning with AI-powered virtual agents. The study addresses the following research question: *How does in-situ reflective learning support facilitate preservice teachers' learning in VR simulation with AI-powered virtual students?*

Literature Review

Teacher Education Using VR simulation

In teacher education, facilitating preservice teacher learning to enact pedagogical practices that approximate expert professionals is essential (Grossman et al., 2009; Ledger et al., 2022). Teacher educators constantly seek to provide sufficient practice experience for preservice teachers (Gundel et al., 2019). Using VR simulation, which provides opportunities for teaching knowledge and skills development as well as reflective practice, appears to be a compelling solution (Dai et al., 2023; Ledger et al., 2022). Teachers can apply knowledge and skills *in-situ* in VR simulation. These affordances of VR simulation are in alignment with the goals of teacher education (e.g., Stroupe & Gotwals, 2018). In other words, VR simulation can facilitate teacher learning with *in-the-moment* reflection and reflective practices (McGarr, 2021). In practice, preservice teachers are situated in simulated environments that provide them with teaching challenges and authentic student discourse and interactions.

To simulate authentic classroom scenarios and settings, research efforts have been invested in designing and implementing simulated virtual students. Simulated virtual students are used in VR to increase realism and presence (Dai, 2023; Ke et al., 2020) as well as to enhance clinical experience of pedagogical decision making (Kavanagh et al., 2020; Ke et al., 2020). Simulated virtual students provided role-play opportunities, embodied student behaviors and thinking processes for preservice teachers to experiment and inquire their pedagogical decisions (Dai et al., 2021; Ke et al., 2020). There are design challenges for creating simulated virtual student agents; for example, low fidelity and convoluted language use that hinder human understanding. As a result, in some cases, integrating automated virtual students in VR simulation has been argued to be *not* compelling to the preservice teachers, while engaging in role-play with peer preservice teachers has been recommended (Ade-Ojo et al., 2022). Research has continued to explore ways and mechanisms that are best applicable to the design and development of virtual agents with natural language communication capabilities. For example, using a mix of human-puppeteered and preprogrammed virtual agents (Ke et al., 2020) or using human actors behind the scene (Chen, 2022).

However, the associated costs for the implementation of human actor-facilitated simulation are barriers for the adoption of such learning technologies (Kaufman & Ireland, 2016). To address the issues of the costs for human-actors behind the scenes and the lack of authenticity in automated virtual students, integrating AI into virtual agents in VR simulations has been suggested to be a design solution (Dai & Ke, 2022).

AI-Powered Virtual Agents Integrated in VR simulation

Natural language processing (NLP) and computing power have greatly improved in recent years, resulting in increasingly applicable AI technologies for educational purposes. AI-powered virtual agents——the virtual simulated humans that are driven by AI for the interactions with human users——have been increasingly used in virtual learning environments to meet learning goals and objectives. In a recent view, Sun et al. (2022) maintained that AI-powered virtual agents are regarded as an essential component in VR simulation. Research on AI-powered virtual agents in VR simulation has been emerging and growing. For example, Nurshatayeva et al. (2021) used AI-powered virtual agents for freshman orientation and the navigation of campus resources. They found that AI-powered virtual agents are effective in improving first-generation students' support-seeking behaviors. Further, Liaw et al. (2023) integrated AI into virtual agents to provide interprofessional communication training for nursing students in VR simulation. Sun et al. (2022) developed an AI chatbot in metaverse to collaborate with human users for the exploration of future earth.

These applications used different AI technologies to realize the affordances. For example, Liaw et al.'s (2023) study used *Dialogflow* engine in Google Cloud that applied NLP to create the conversational AI. Sun et al. (2022) used *dreamily.ai* as the generative AI technology for text generation. Additionally, Large Language Models (LLMs) or transformer-based language models have been increasingly available, integrating LLMs in learning environments has become one feasible way to support inquiry-based teaching and learning (Dai & Ke, 2022).

Learning Support in VR Simulation

Learning support is important in inquiry-based learning as it acts as a critical instrument for learners when they are experimenting and exploring in VR. With learning support, "a learner can attain a goal or engage in a practice otherwise out of reach" (Davis & Miyake, 2004, p. 266). Studying learning support in VR simulation has been primarily focused on K-12 education and limited to teacher learning despite the needs. For example, Puntambekar and Kolodner (2005) discussed learning support being used for science inquiry in classrooms, originated from Vygotsky's (1978) scholarship suggesting that "a more knowledgeable person guides a learner's emerging understanding" (Puntambekar & Kolodner, 2005, p. 188). Nowadays, the study of learning support is not only limited to human to human (Bruner, 1975) but also evolved to include computers and software (Puntambekar, 2022).

In computer-based digital learning environments, there are different forms of learning support commonly used, such as modeling, hints, prompts, demonstration videos, role-play, reflection guides, or worked examples (e.g., Chernikova et al., 2020; Shute et al., 2021). In teacher education, case analysis can also be used as an *in-situ* reflective tool (Grossman et al., 2009). Essentially, the design of learning support should consider the learners' accountability and responsibility (Puntambekar, 2022).

Theoretical Framing for the Current Study

The current study draws upon the literature in *teacher education in VR simulation*, *AI-powered virtual agents integrated in VR simulation*, and *learning support in VR simulation* to explore the use of *in-situ reflective learning support* in VR simulation for preservice teacher learning. Specifically, the literature supports the understanding of how *in-situ reflective learning support* plays a constructive role when preservice teachers are engaged in situational practice in VR simulations, where they experiment with pedagogy through interactions with AI-powered virtual agents. These elements together provide a comprehensive foundation for immersive and productive teacher learning experience in VR simulation.

Method

Research Design

In this descriptive case study (Yin, 2018), I explored the interactions and dynamics between preservice teachers, AI-powered virtual student agents, and the *in-situ* learning support. Each participant bounded in time and space and hence was considered as a unique case. I used purposeful sampling to recruit and identify participants that can provide detailed and in-depth information for the research question, from a larger study. The criteria for sampling were as follows: 1) students enrolled in a college of education, 2) completed the study session, and 3) used *in-situ* learning support in the VR simulation. The voluntary participants were recruited from different institutions and through a professional organization's online communication channel in the US. Nineteen participants (n_{female} = 13, 68%) met the inclusion criteria in this study; they self-reported an average of approximately 18.58 months of teaching experience, including both formal instruction and informal tutoring.

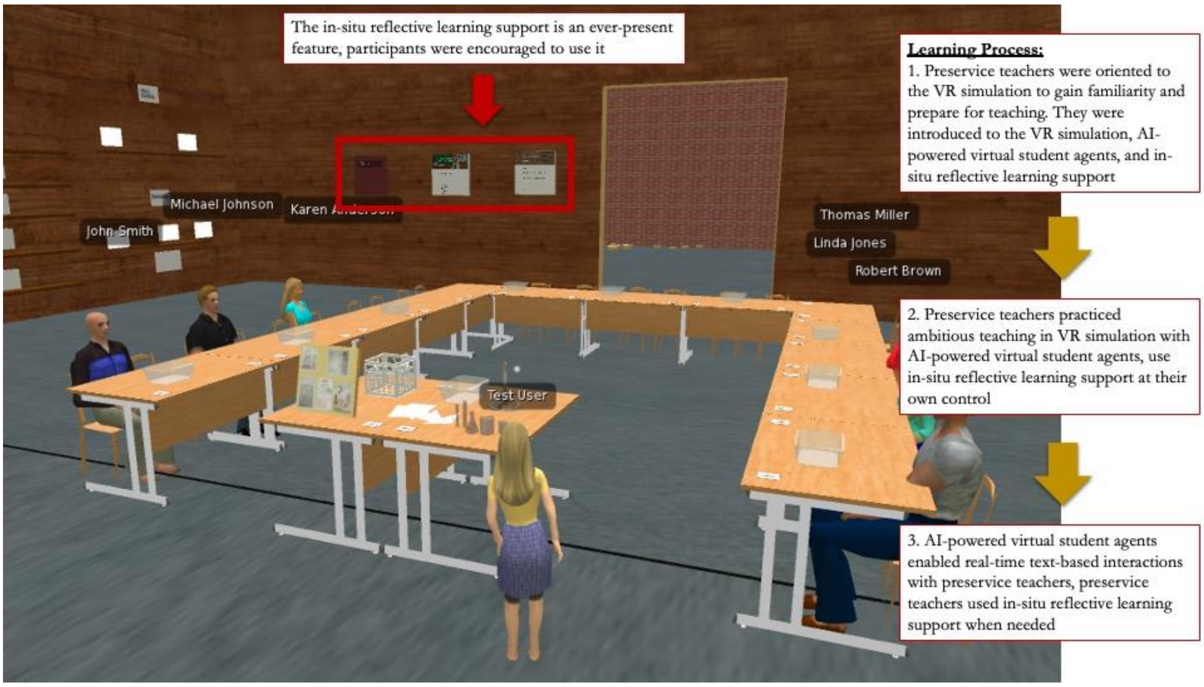
Each participant joined a scheduled video-conferencing call via Zoom with a facilitator/researcher (a 2-hour session). After an introduction and consent, the facilitator/researcher logged in the VR simulation learning environment, shared their screen of the VR simulation, and granted control of their computer to the participant via Zoom. The participants were given the opportunity to familiarize and prepare for the mini-lesson before they started the teaching practice in the VR simulation; they were also introduced to the *in-situ* reflective learning support. The participants used the *in-situ* learning support with an average of 158.16 seconds and a median of 94 seconds.

The Designs of *in-situ* Learning Support and AI-Powered Virtual Students in the VR Simulation

The *in-situ* learning support (see Figures 1 and 2) was defined as a tool designed to assist learning when preservice teachers are practicing teaching in the VR simulation as part of the situated learning experience. The *in-situ* learning support was designed to be integrated into the VR learning environment called *EVETeach* (Ke et al., 2023). During the learning experience in VR, preservice teachers have access to the *in-situ* learning support, and they were encouraged to use it. Using an authoring tool, *in-situ* learning support was designed to provide situated practice with *question scaffolds*, *prompts*, and *situational case analysis* (Dai, 2023; Grossman et al., 2009). The *in-situ* learning support was designed based on the literature. For example, it was ever-present at the participants' own control, a design decision made to support learner's autonomy (e.g., Dai et al., 2023). Additionally, the *in-situ* learning support also emphasized preservice teachers' accountability and responsibility (Puntambekar, 2022) in learning and practice pedagogical reasoning (Kavanagh et al., 2020). In other words, no direct answers or solutions for pedagogical dilemmas (Kavanagh et al., 2020) were provided to preservice teachers; instead, they were expected to exercise reflective practices and applied pedagogical problem solving.

The learning support was integrated in *EVETeach* (Ke et al., 2023). *EVETeach* was designed and developed in *OpenSimulator*, an open-source VR platform, to support teacher learning (created in the lab at Florida State University directed by Fengfeng Ke, Ph.D.). AI-powered virtual student agents called *Evelyn* in the VR simulation learning environment provided real-time adaptive interactions with preservice teachers. An LLM (i.e., Generative Pre-trained Transformer-2, GPT-2) from *OpenAI* was integrated into *EVETeach* (Ke et al., 2023). The research team customized the LLM with classroom data, in which the teachers adopted ambitious science teaching (Windschitl et al., 2018). The customization is a practice to design the AI technology for local educational purposes (Dai & Ke, 2022). The preservice teachers practiced biology with the AI-powered virtual student agents. They primarily focused on two stages: *engagement* and *consensus building*, in science teaching and learning. The interactions were text-based in *OpenSimulator*, and the text-based interactions were recorded in the VR dialogue panel, preservice teachers have access to their own classroom interaction records for reflective practice.

Figure 1
An illustration of the in-situ reflective learning support and the learning process in the VR simulation



The in-situ reflective learning support is an ever-present feature, participants were encouraged to use it

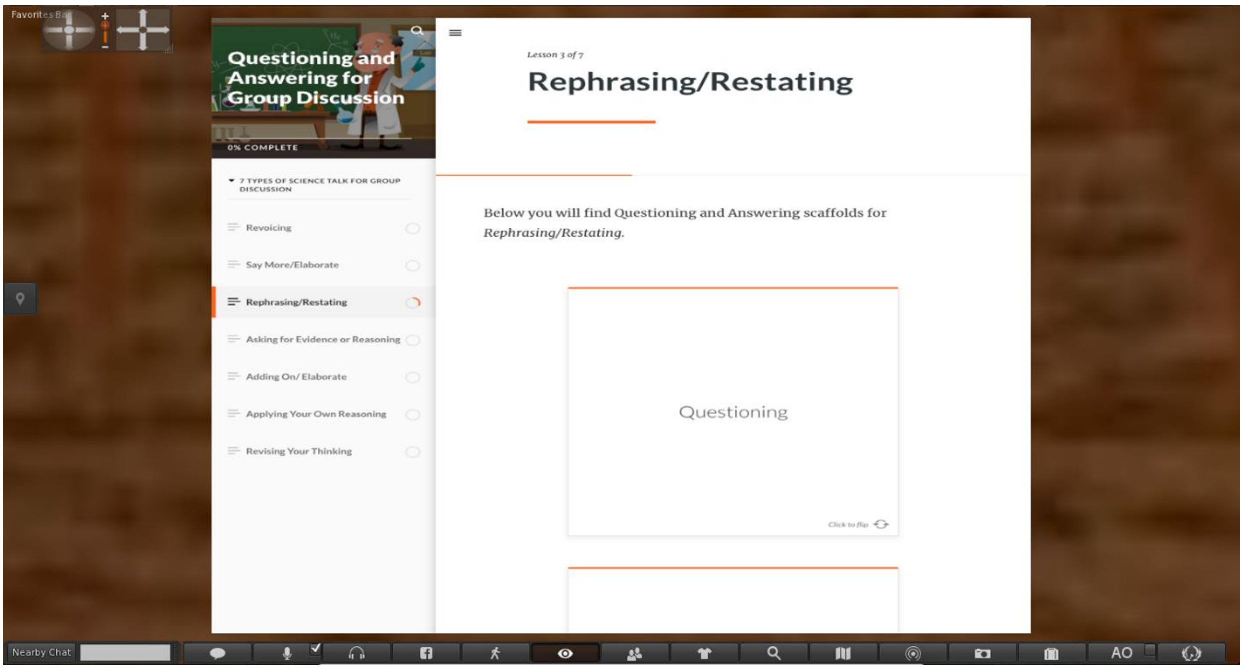
Learning Process:

1. Preservice teachers were oriented to the VR simulation to gain familiarity and prepare for teaching. They were introduced to the VR simulation, AI-powered virtual student agents, and in-situ reflective learning support

2. Preservice teachers practiced ambitious teaching in VR simulation with AI-powered virtual student agents, use in-situ reflective learning support at their own control

3. AI-powered virtual student agents enabled real-time text-based interactions with preservice teachers, preservice teachers used in-situ reflective learning support when needed

Figure 2.
An example of the in-situ learning support integrated in the VR simulation (hints)



Questioning and Answering for Group Discussion

0% COMPLETE

7 TYPES OF SCIENCE TALK FOR GROUP DISCUSSION

- Revoicing
- Say More/Elaborate
- Rephrasing/Restating
- Asking for Evidence or Reasoning
- Adding On/ Elaborate
- Applying Your Own Reasoning
- Revising Your Thinking

Lesson 3 of 7

Rephrasing/Restating

Below you will find Questioning and Answering scaffolds for *Rephrasing/Restating.*

Questioning

Click to flip

Data Collection

I collected data from multiple sources including participatory observations, think-aloud protocol, semi-structured interviews (during situated practice and after the experience), audio- and video-recordings, and computer logs of the human-AI conversations (i.e., teacher-student conversations). The protocol for the multiple data sources focused on the situated interactions between the preservice teachers, the AI-powered virtual student agents, and the *in-situ* learning support. Multiple data sources ensured triangulation for trustworthiness and credibility (Miles et al., 2020).

Data Analysis

The collected data were analyzed in the first round with open coding techniques. In the second cycle, I used cross case analysis to compare the data to make sense of the unique phenomenon (Miles et al., 2020). Specifically, the analyses focused on how the use of *in-situ* reflective learning support influenced preservice teachers' pedagogical practices. That is, the analyses emphasized the instances where participants used the *in-situ* reflective learning support, and the subsequent pedagogical practices observed. The data presented was anonymized with a code, for example, P01 represented participant number one.

Results

In the following section, three major themes emerged from the data analyses are presented. These themes focus on how preservice teachers interacted with the *in-situ* reflective learning support, along with AI-powered virtual student agents in VR, facilitated the cultivation of pedagogical practices. The emerged pedagogical phenomena resulted from interactions among the *in-situ* reflective learning support, AI-powered virtual agents, and preservice teachers, aligning with the research question and data analyses.

Collective Reasoning with AI-Powered Virtual Students that Builds Productive Discourse

With the help of *question scaffolds* and *prompts* in the *in-situ* learning support, preservice teachers were actively orchestrating students' ideas and resources, when encountering pedagogical quandaries. For example, P11 honed her pedagogical orchestration skills to foster constructive discourse within the classroom, driving the collective science reasoning of the class. Facilitating the AI-powered students' scientific reasoning in class requires persistent and iterative efforts of ambitious science teaching practice by probing students' ideas and facilitating classroom discourse. In the following event, P11 interacted with AI-powered virtual students——Robert, John, Michael, and Karen to create productive classroom discourse collectively:

> **P11:** How does decomposition start?
> **Robert:** How does it get broken down?
> *[P11 think-aloud: at least he started to think, so I could ask him…um…]*
> **P11 to Robert:** What are some ways you've seen materials be broken down?
> **Robert:** Uh, water.
> *[P11 think aloud: that's a good one, um… And I could ask the class as a whole if they have any related experience.]*
> **P11 to the class of AI-powered virtual students:** Does anyone have anything to add to Robert's response?
> **John:** Well, I think that, uh…I think we've covered that in class today.
> **P11 to John:** "Yes, we've covered the two ways…" *[revised text input by deleting "the two ways" and making a new input——a more specific and inquiry-based one]* "Yes, we've covered how materials are decomposed through what ways?"
> **John:** The way fungus digests food.
> *[P11 think aloud: oh great, yes! So, he's getting the class to talk in the right direction, so I can ask the class as a whole then, um…how…what steps do fungi use to decompose materials.]*
> *[Reviewed the recorded conversation logs in the VR dialogue panel, analyzed the word "digest," a scientific word John used: he's thinking fungi is "eating," like "digesting" the food, like the materials, which is not necessarily correct, it's more breaking them down and taking the nutrients back]*
> **P11 to the class of AI-powered virtual students:** Yes, fungi break down materials, but do they digest them?
> **John:** No, they don't digest food.
> ………
> *[P11 think aloud: there are many ideas flying around. I could ask Karen]*
> **P11 to Karen:** Karen, do you think fungi are absorbing to get bigger?
> **Karen:** I think fungus is getting smaller.
> *[P11 think aloud: that probably indicated that she thinks it's breaking down. So I could address the class as a whole]*
> **P11 to the class of AI-powered virtual students:** What do you think is absorbed by fungi to make them bigger?
> **Michael:** Um, the enzymes that break down food.
> *[P11 think aloud: Yes, I did it!]*

In the after-experience interview, P11 reflected the collective reasoning experience facilitated by the learning support and afforded by the class of AI-powered virtual students, "*so for the start, there were only like two students responding to my lesson, they were like the only two who want to engage…and then at the end, I feel like I got all students to be engaged in the lesson which I am happy about, and they were giving me pretty consistent responses with, like, what they were thinking.*" Contemplating about her pedagogical strategies, P11 reasoned: "*I think the constant…like…repetition of asking questions definitely helped with getting more students engaged by rewarding questions, so I feel like just like hounding in the questions, and like asking for one student to elaborate and what they thought, and then going to the full class, and asking them if they had anything to add on to that; because it gives students more of that opportunity to build off of each other and feel less intimidated.*"

Intentional Practice to Probe and Inquire AI-Powered Virtual Students' Scientific Reasoning

Preservice teachers developed an increased awareness and acute sensitivity to the scientific reasoning processes of AI-powered virtual students. Their pedagogical practices shifted from neglecting students' input to deliberately focusing on students' resources following the interactions with the *in-situ* learning support. In the following event, P14 interacted with the AI-powered virtual student (named *Linda*), and the *in-situ* learning support:

> **P14:** Does anyone know what kind of food fungi can grow on?
> **Linda:** Um, on decaying wood.
> **P14:** Oh well, does anyone have any other ideas?
> [Checked the *in-situ* learning support (i.e., situational case analysis)]
> **P14:** I think they [the student in the example of the situational case analysis in the *in-situ* support] are nervous.

In the above event, P14 interacted with Linda but the response of Linda as an AI-powered virtual student did not seem to register in P14's pedagogical reasoning schema, P14 neglected Linda's response and continued to solicit more ideas from the class and other AI-powered virtual students. However, after analyzing the example case in the *in-situ* learning support, P14 situated in students' perspective, and tried to reflect on what could be done differently and more intentionally. P14 acknowledged the keywords in Linda's idea. Responding to Linda's idea (i.e., "*Um, on decaying wood*"), P14 stated: "*I think I possibly will ask more about environmental factors*."

During the interview after the situational practice, P14 was being asked "did this scenario help you to practice?" P14 responded: "Yeah, I would probe more about students' ideas and I would think more about the use of students' ideas [in the classroom discussion]." P14 recalled the above event and suggested that this particular event was instrumental in his revision of thinking for teaching.

In the following event, after P14 reflected on the *in-situ* learning support (situational case analysis), he revised his teaching strategies. P14 was more intentional and deliberate in responding to and elaborated on students' scientific reasoning assets. He discussed with Robert, an AI-powered virtual student, in the scenario:

> **P14:** In what way do you think fungi help to break down yeast and salt?
> **Robert:** Enzymes are breaking things down.
> **P14:** Can you tell us what enzymes are?
> **Robert:** Enzymes are the chemicals that are released by the cell membrane
> **P14:** What do you think enzymes do when they are released?
> **Robert:** It breaks down the organic material into simple sugars and gives it to the cell membrane.

Analyzing Developmentally Aligned AI-Powered Virtual Students' Discourse in-situ

Another theme emerged as a salient phenomenon of the interactions focused on preservice teachers' adaptation to the AI-powered virtual student agents' cognitive development stage, facilitated by the use of *in-situ* learning support. The cognitive development stage of the AI-powered virtual students was demonstrated by their discursive style. In the following example from a longer conversational turn, AI-power virtual students responded in a way that demonstrated mixed states of understanding and confusion, suggesting a current idea of "fungi eat humans is beneficial to humans." Applying skills learned from *situational case analysis* in the *in-situ* learning support, the preservice teacher analyzed the response and took up ambitious teaching practices to acknowledge students' ways of thinking (representing their developmental stage) and continue to probe students' ideas (italicized below), finally, AI-powered student used keywords (i.e., hosts) in the discussion of fungi, demonstrating improved understanding:

> **P08:** Do you think fungi is beneficial for us?
> **Student:** Yeah.
> **P08:** Can you elaborate more on how fungi [are] beneficial for us?
> **Student:** They eat us
> **P08:** *Interesting! Do you think fungi eat us? How?*
> **Student:** They eat our guts and we don't……
> **P08 to the class:** What do you all think? [When] fungi can eat us when we [are] dead or when we [are] [a]live?
> **Student:** They can eat our hosts.

The above interactions suggested that the *in-situ* learning support designed and AI-powered students' responses prompted preservice teachers to be sensitive to students' ideas and developmental stage, and being mindful in making pedagogical decisions that will further the scientific discussion. Corroborated by P11, she added that: "*I tried to kind of validate what they were saying with their input…I mean nothing that they presented was essentially incorrect…more just a kind of basic understanding rather than like a depth knowledge which I would prefer for them to have so just kind of validating what they were saying to me. But then also kind of redirecting that into a more scientific one.*"

Discussion and Conclusion

In this case study, preservice teachers were supported by the *in-situ* reflective learning support with *question scaffolds*, *prompts*, and *situational case analysis* in a VR simulation with AI-powered virtual student agents. Three major themes supported the design and implementation of the *in-situ* reflective learning support and AI-powered virtual students in VR simulation for preservice teachers. The three themes highlighted improved teacher noticing and awareness of student performance with ambitious science teaching (Windschitl et al., 2018) facilitated by the *in-situ* reflective learning support. The current study extended learning support studies to the contexts of the intersections of teacher education, VR simulations, and AI in education. Specifically, the study expands the literature of learning support from K-12 contexts (Puntambekar & Kolodner, 2005) to teacher education, suggesting that learning support should be used to help preservice teachers to engage in reflective practice and exercise pedagogical reasoning. The effective teaching practices manifested in three distinct ways. First, they involve engaging in class-based interactions with various students to collectively build meaningful scientific discourse as a class. Second, they require a deliberate effort to analyze students' responses. Third, they entail aligning teaching with students' developmental stages. The observed effective teaching practices suggest that the use of in-situ reflective learning support contributes to iterative and intentional pedagogical decision making, enabling novices' pedagogical trajectories to become adaptive and responsive (Kavanagh et al., 2020). The study also advocates using diverse forms of *in-situ* reflective learning support to cater to different instances and interactions. Specifically, *scaffolds*, *prompts*, and *situational case analysis* were found to facilitate different subsequent pedagogical decision-making enactments.

This study provides useful exploratory insights and heuristics on the interactions between preservice teachers and the *in-situ* reflective learning support in VR simulations with AI-powered virtual students. Future research should consider providing adaptive *in-situ* reflective learning support to preservice teachers by gauging preservice teachers' situational pedagogical practices using NLP and machine learning algorithms. Further, while all forms of learning support are meaningful in the current study, future research should examine the nuanced differences between various forms of learning support in VR simulation with AI-powered virtual agents for teacher learning.

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