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Seeking to support preservice teachers' responsive teaching: Leveraging artificial intelligence-supported virtual simulation

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Abstract

Preparing preservice teachers (PSTs) to be able to notice, interpret, respond to and orchestrate student ideas—the core practices of responsive teaching—is a key goal for contemporary science and mathematics teacher education. This mixed-methods study, employing a virtual reality (VR)-supported simulation integrated with artificial intelligence (AI)-powered virtual students, explored the frequent patterns of PSTs' talk moves as they attempted to orchestrate a responsive discussion, as well as the affordances and challenges of leveraging AI-supported virtual simulation to enhance PSTs' responsive teaching skills. Sequential analysis of the talk moves of both PSTs ($n = 24$) and virtual students indicated that although PSTs did employ responsive talk moves, they encountered difficulties in transitioning from the authoritative, teacher-centred teaching approach to a responsive way of teaching. The qualitative analysis with triangulated dialogue transcripts, observational field notes and semi-structured interviews revealed participants' engagement in (1) orchestrating discussion by leveraging the design features of AI-supported simulation, (2) iterative rehearsals through naturalistic and contextualized interactions and (3) exploring realism and boundaries in AI-powered virtual students. The study findings provide insights into the potential of leveraging AI-supported virtual simulation to improve PSTs' responsive teaching skills. The study also underscores the need for PSTs to engage in well-designed pedagogical practices with adaptive and in situ support.

KEYWORDS
artificial intelligence, preservice teachers, responsive teaching, science and mathematics education, teacher education, virtual simulation

Practitioner notes

What is already known about this topic

- Developing the teaching capacity of responsive teaching is an important goal for preservice teacher (PST) education. PSTs need systematic opportunities to build fluency in this approach.
- Virtual simulations can provide PSTs with the opportunities to practice interactive teaching and have been shown to improve their teaching skills.
- Artificial intelligence (AI)-powered virtual students can be integrated into virtual simulations to enable interactive and authentic practice of teaching.

What this paper adds

- AI-supported simulation has the potential to support PSTs' responsive teaching skills.
- While PSTs enact responsive teaching talk moves, they struggle to enact those talk moves in challenging teaching scenarios due to limited epistemic and pedagogical resources.
- AI-supported simulation affords iterative and contextualized opportunities for PSTs to practice responsive teaching talk moves; it challenges teachers to analyse student discourse and respond in real time.

Implications for practice and/or policy

- PSTs should build a teaching repertoire with both basic and advanced responsive talk moves.
- The learning module should adapt to PSTs' prior experience and provide PSTs with in situ learning support to navigate challenging teaching scenarios.
- Integrating interaction features and AI-based virtual students into the simulation can facilitate PSTs' active participation.

INTRODUCTION

In a classroom setting, student learning of science and mathematics depends greatly on the idea exchange between students and teachers (Ball & Forzani, 2011). Effective teaching involves teachers fostering epistemic practices through noticing, extending, orchestrating and responding to students' ideas (NCTM, 2000; NRC, 2012). Teachers should actively guide students in constructing knowledge, integrating core content and providing equitable learning opportunities (NGSS Lead States, 2013). Responsive teaching, a pedagogy where teachers foreground and centre the instruction on the substance of students' thinking, has emerged in recent years as a promising approach to support student learning (Van Es & Sherin, 2008; Watkins et al., 2020). By taking students' everyday sense-making, questions and confusions seriously, responsive teaching can increase students' engagement, support disciplinary learning and promote equitable participation (Thompson et al., 2016;

Warren et al., 2001). While there is a general consensus that developing the teaching capacity of responsive teaching is one of the important goals for preservice teacher education (Kloser, 2014; Levin et al., 2009; Robertson & Richards, 2017), questions persist regarding how to prepare preservice teacher (PST) learning to enact these high-leverage teaching practices in their classrooms.

Recent research advocates employing virtual simulation in teacher education to expand the range and quality of PSTs' teaching repertoire (Ke et al., 2021; Ledger et al., 2022). Virtual simulations can present a realistic experience in which teachers can roleplay with simulated scenarios to practice principles of pedagogy (Dieker et al., 2014). Engaging in teaching practices within virtual simulations enhances PSTs' awareness of how teacher actions impact student learning. It also develops their ability to attend to individual students and enact inclusive teaching practices (Ke et al., 2020; Lin, 2023; Quintana & Fernández, 2015; Rayner & Fluck, 2014). Moreover, the advancement in artificial intelligence (AI) inaugurates exciting possibilities for personalized and experiential learning in simulation-based teacher education (Barrett et al., 2024; Dai & Ke, 2022). Specifically, AI-powered virtual students can be integrated into virtual simulations to create greater synergy that increases PSTs' sense of presence, engages PSTs in authentic discourse and supports their practice of decomposed teaching skills (Dai et al., 2024; Ke et al., 2016; Ledger et al., 2022; Lee et al., 2024). However, there has been a dearth of research that explores the use of AI-supported virtual simulation to improve PSTs' responsive teaching.

While virtual simulations provide immersive, iterative practice opportunities for PSTs to facilitate approximations of teaching (Ledger et al., 2022; Theelen et al., 2019), little is known about how the AI-supported learning experience can be tailored to promote PSTs' responsive teaching. Therefore, the current study aimed to explore how PSTs practice responsive teaching of science and mathematics in an AI-supported virtual simulation, as well as the affordances and challenges of the simulation to support their practice.

Specifically, we seek to answer two research questions:

1. What are preservice teachers' discourse patterns when interacting with AI-powered virtual students in the virtual simulation?
2. What are the affordances and challenges of AI-supported virtual simulation for preservice teachers to practice responsive teaching?

Practicing responsive teaching

The premise of responsive teaching lies in the belief that students are endowed with rich resources for understanding and structuring scientific inquiry (Duckworth, 2006; Hammer et al., 2012; Metz, 2011). Teachers' role is to identify productive beginnings in student ideas and orchestrate discussion to support disciplinary reasoning and learning activities that build on those ideas (Robertson & Richards, 2017). By positioning students as integral participants of learning, centering discussion on their thinking and building connections between the discipline and students' ideas, responsive teaching prompts students' active participation, engages them in generative sense-making and improves their conceptual understanding (Engle, 2006; Levin et al., 2009; Schwarz et al., 2017; Stroupe, 2014).

Despite the promises of responsive teaching, it remains a challenge for many teachers, particularly PSTs, to practice this teaching approach (Hammer et al., 2012; Lampert, 2001). Being responsive to student ideas requires not only models of expertise but also systematic opportunities for PSTs to build fluency with the responsive way of teaching (Osborne et al., 2013). PSTs need opportunities that support their learning in noticing, analysing and leveraging the resources and diverse ideas that students bring into the classrooms (Pimentel

& McNeill, 2013; Teo, 2016). As such, practice-based learning, the approach for teachers to practice approximated components of core teaching practices, has been proposed to improve teachers' responsive teaching skills (Grossman et al., 2009). Through focused and purposeful practice, PSTs experiment with the skills and new roles and make connections between learning in teacher education and practice in the field (Grossman et al., 2009).

The role of teacher talk

This study is conceptualized from a sociocultural perspective (Vygotsky, 1978, 1986; Wertsch, 1991), which emphasizes the importance of social interaction and language use in individuals' learning and cognitive development. Teacher talk plays a pivotal role in student learning as it serves as a primary medium through which social interactions, norms and cultural knowledge are transmitted and negotiated in classroom settings (Blanton et al., 2001; Mercer & Littleton, 2007). The ways teachers construct questions and orchestrate discussions have strong impacts on the dynamics of student discussion and their learning outcomes (Mercer & Littleton, 2007; Pimentel & McNeill, 2013).

Responsive talk moves involve active interactions with student thinking through revoicing, asking series of follow-up questions and purposefully eliciting clarification to facilitate connections between student contributions and disciplinary concepts (Brodie, 2011; Colley & Windschitl, 2016; Goodhew & Robertson, 2017). These talk moves encourage students to articulate their reasoning process, clarify any ambiguities and modify their hypotheses (Webb et al., 2009). More importantly, employing responsive talk moves is communicating the expectation that students' ideas and thinking are resourceful and valued, and teachers are interested in knowing students' in-process thinking rather than correct answers (Pimentel & McNeill, 2013; Walshaw & Anthony, 2008; Webb et al., 2009). Research has consistently shown the positive influence of adopting responsive talk moves on the quality and depth of student explanation and their conceptual understanding (Grinath & Southerland, 2019; Kang et al., 2014; Levin et al., 2012; Webb et al., 2009).

Practicing teaching in virtual simulations

Virtual simulations afford a controlled environment that provides teachers with cyclical opportunities to practice teaching skills without the risk of negatively impacting real students (Dalinger et al., 2020; Dieker et al., 2014). This form of learning, compared to observing veteran teachers in field experiences, offers a more authentic, interactive practice (Dalinger et al., 2020; Ke et al., 2016). Within virtual simulations, teachers role-play with diverse scenarios or virtual students (eg, controlled by peer teachers) to carry out the interactive work of teaching (Lee et al., 2024; Mikeska et al., 2023). Studies have reported that practicing teaching in virtual simulations can improve teachers' learning outcomes, such as inclusive classroom practices (Ke et al., 2020; Lin, 2023; Rayner & Fluck, 2014) and general teaching skills, including discourse skills (Ke et al., 2016; Ledger et al., 2022; Lee et al., 2024).

In response to the growing demand for personalized and experiential learning, AI tools, especially generative AI or large language models, have emerged as transformative resources for teacher preparation (Dai & Ke, 2022). For instance, Demszky et al. (2023) developed a generative AI tool capable of providing automatic feedback to teachers on their uptake of student ideas. It was found teachers who received the feedback performed significantly better in appreciating students' contributions, a core practice in responsive teaching approaches. In virtual simulations, AI tools have found application in developing AI-powered virtual students, which provide authentic learning opportunities for PSTs to practice and develop teaching skills. For example, Dai et al. (2024) explored PSTs' experience of teaching AI-powered virtual students in a virtual simulation and found that the virtual students can generate authentic discourse that facilitated PSTs' pedagogical reasoning and decision-making.

Despite these promising developments, there is scant research that examines the prospects of leveraging AI-supported virtual simulation to improve PSTs' responsive teaching skills. Therefore, we aim to initiate this critical research discourse by exploring PSTs' discourse patterns with AI-powered virtual students, as well as the affordances and challenges of AI-supported virtual simulation in enhancing their responsive teaching skills.

METHOD

This study employed the concurrent mixed-methods research approach (Creswell & Plano Clark, 2018), which collects quantitative and qualitative data simultaneously to provide a holistic understanding of PSTs' experience of practicing responsive teaching in an AI-supported virtual simulation. Findings from the quantitative and qualitative data analyses were congregated and corroborated to address both research questions. We used quantitative sequential analysis (Bakeman & Quera, 2011; Suen & Ary, 2014) to identify PSTs' responsive teaching patterns in teaching AI-powered virtual students. We also employed a qualitative case study (Yin, 2017) to further explore the affordances and challenges of AI-supported virtual simulation for enacting responsive teaching, which corroborates the sequential data mining results and provides further insights.

Participants

A total of 24 PSTs were recruited from a large research university in the Southeastern U.S. Nineteen reported as female and five reported as male. Participants had varying levels of experience related to teaching, such as practicum experiences, lesson planning and delivery, or student teaching (ie, No experience = 50%, Less than two years = 33%, More than two years = 17%).

EVETeach: The AI-supported virtual simulation

To support PSTs' development of responsive teaching skills in science and mathematics classrooms, *EVETeach* (Enactive Virtual Environment for Teaching, Ke et al, 2021) was designed and developed in an open-source virtual environment *OpenSimulator* (OepnSimulator, n.d.). Resembling a real-world classroom, the virtual simulation was equipped with (1) science and math simulated scenarios; (2) six AI-powered virtual students; (3) interactive teaching aids, including whiteboards, media boards and notecards; and (4) text and voice channels that enable PSTs to interact with human training facilitators (Figure 1). Adopting a constructivist approach to learning, participants' practice was guided by the 5E model of inquiry-based instruction (engage, explore, explain, elaborate and evaluate; Bybee, 1990). PSTs are expected to employ and practice discourse skills to engage virtual students, elicit student ideas, orchestrate critical discussion and support consensus building on the introduced topic.

AI-powered virtual students were driven by a student model named *Evelyn*, which was developed by refining Generative Pre-trained Transformer (GPT), a large language model developed by OpenAI (Radford et al., 2019). For designing and customizing the language model for our specific purposes, we first collected and transcribed a collection of 33 real

FIGURE 1 The interface of AI-supported virtual simulation.

classroom recordings, mainly from TIMSS (https://nces.ed.gov/timss/) and Ambitious Science Teaching (https://ambitiousscienceteaching.org/), which were used for training and localization of the language model that drives *Evelyn*. *Evelyn* underwent iterative training and testing to generate real-time, contextualized responses to various inputs. The interaction with virtual students in this study was text-based, where participants would address the whole class or individuals by clicking on different correspondence gadgets. More details on the *Evelyn* student model can be found in Appendix A.

Procedure and data collection

Participants joined the virtual session independently, observed and assisted by a trained human facilitator online. Participants completed the consent form and a brief demographic survey before the session. Participants were oriented through several training modules on how to teach virtual students, followed by their interacting with a sample virtual student to familiarize themselves with the manoeuvre in the simulation. Participants then practiced teaching virtual students in the simulation for at least one hour focusing on two teaching stages of ‘engagement’ and ‘consensus building’, and the participants were encouraged to think aloud (Van Someren et al., 1994). After the session, the facilitator fostered experience reflection and administered a semi-structured interview to elicit individual participants' perception and explanation of their teaching experiences and pedagogical decision-making processes. The teaching sessions were audio- and screen-recorded. Data from video recordings, interaction transcripts, observational notes and interview transcripts were collected.

TABLE 1 Teacher talk move coding scheme.

	Codes	Description	Source
Productive Responsiveness	Follow-up	Teachers pursue students' disciplinary thinking by asking open-ended questions for clarification or explanation	Brodie (2011)
	Revoice	Teachers synthesize students' ideas and/or revoice them with disciplinary concepts	Goodhew and Robertson (2017)
	Counterclaim	Teachers challenge student thinking by guiding student attention to phenomenon that contradicts student assumption	Pierson (2008), Teo (2016)
	Connect	Taking up one student's idea or question as a whole-class activity, inviting students to respond	Goodhew and Robertson (2017)
	Attend to alternative explanations	Teachers ask students questions to explore how they developed the alternative explanations and scaffold them to modify their claims	Pierson (2008), Colley and Windschitl (2016)
	Use contextualized examples	Teachers use contextualized examples to promote connection between everyday experience and disciplinary thinking	Goodhew and Robertson (2017)
	Question modification	Repeating, simplifying or rephrasing the questions	Zerai et al. (2023)
	Attend to specific students	Teachers move from group discussion to attending specific students to promote engagement	Developed from data
Unproductive Responsiveness	Direct answers	Teachers directly answer students' questions correctly without prompting	Pierson (2008)
	Assessment	Teachers focus on evaluating students' ideas as right or wrong	Pierson (2008), Estapa et al. (2022)
Neutral	Pragmatic	Teachers manage the classroom or use functional discourse	Dyer and Sherin (2016)

Data analysis

Sequential analysis

To examine the discourse patterns, both teacher and student talk moves were labelled first. Using dialogue transcripts, we coded all talk moves adopting a combination of inductive and deductive processes. For the deductive process, we referenced existing frameworks in the literature to inform our coding (see more in Tables 1 and 2). Adapted from previous research (eg, Dyer & Sherin, 2016; Pierson, 2008), we classified different types of responsiveness in teacher talk into three categories: productive, neutral and unproductive responsiveness. Specifically, productive responsiveness refers to talk moves that build on student ideas and are conducive to students' discussion and thinking (eg, teachers ask follow-up questions to understand student thinking). Neutral productiveness refers to pragmatic talk moves that move teaching forward, including class management and functional discourse (eg, the objectives of the activity are …). Talk moves with unproductive responsiveness tend to adopt a

TABLE 2 Student talk move coding scheme.

Codes	Description	Source
Off-topic	Statements or questions that are off the topic of the inquiry	Lipponen (2000)
Silence	Students remain silent	Informed by *Evelyn*
Simple answer	Students give simple answers to a question	Informed by *Evelyn*
Explanation with supporting evidence	Students explain the phenomenon with supporting reasons and evidence	Informed by *Evelyn*
Explanation with partial understanding	Students explain the phenomenon with partial understanding	Informed by *Evelyn*
Alternative explanation	Students provide explanations in disagreement with existing explanations	Tao and Zhang (2018)
Questions for deeper understanding	Questions requesting clarification, confirmation or explanation	Chin and Brown (2002), Lipponen (2000)
Questions for factual information	Questions or statements seeking factual information	Chin and Brown (2002), Lipponen (2000)

traditional view of teaching, where teaching is framed towards delivering facts or canonical knowledge.

Additionally, *Evelyn* was designed to dynamically portray various levels of basic knowledge, cognitive/affective states and engagement in class. To capture the dynamics and nuance of the exchanges that are yet to be fully explored in the literature, we implemented an inductive process to generate a few a priori codes.

Two coders were trained and coded the same 30% of the data independently, the inter-rater reliability was 92.6%. The coders then met every week for a month to calibrate the coding. The disagreement was discussed and resolved before they coded the rest of the data independently. Examples of the codes are shown in Appendices B and C.

For sequential analysis, this study reported multiple measures for quantitative behavioural observation research (Bakeman & Quera, 2011; Suen & Ary, 2014), including association rule mining, Yule's *Q* and Markov Model transition matrix.

Using association rule mining, an important technique in data mining that uncovers interesting correlations between items in a transaction database (Kotsiantis & Kanellopoulos, 2006), we analysed talk moves from both PSTs and virtual students. Data cleaning resulted in 2586 talk moves, which were grouped into 437 sequences, each containing six talk moves. Association rule mining was conducted in two steps. First, we identified all frequent items, or talk moves, whose occurrences exceed a predetermined threshold or 'support' of 0.05 (occurring in at least 5% of the sequences). Second, we generated association rules from the frequent item sets based on two metrics, confidence and lift. Confidence measures the conditional probability that consequent behaviour will occur given that the antecedent behaviour has occurred (larger values mean higher confidence). Lift measures the performance of an association rule to determine whether there is a significant association between two items (larger values implying a positive effect). We filtered out the patterns with lift values less than 1.2. Additionally, we calculated Yule's *Q* for each pattern. Yule's *Q* is a statistical measure that quantifies the association between two variables (Yule, 1927), with absolute large values indicating strong positive or negative correlations (Bakeman & Quera, 2011). In this study, we set the cutoff value for Yule's Q at 0.4.

Lastly, a Markov Chain transition matrix is a stochastic matrix that describes the possibilities of transitioning from one state to another in a discrete-time Markov Chain (Suen & Ary, 2014). We calculated the Markov Chain transition matrix and drew the state transition diagram to visualize the conditional transitions from virtual student talk moves to those of PSTs. A Chi-square test of independence was used to test the significance of transition probabilities.

Thematic analysis

To gain fine-grained insights into how PSTs' responsive teaching practices interacted with AI-powered virtual students, a qualitative thematic analysis was also performed. We triangulated data from video recordings, dialogue transcripts, observational notes and semi-structured interviews to identify salient themes of the affordances and challenges of practicing responsive teaching in virtual simulations (Patton, 1999). The qualitative data analysis involves open, axial and selective coding to reveal the key themes (Strauss & Corbin, 1998) depicting the learning experiences in AI-supported virtual simulation. Peer checking, an iterative process of discussion and consensus building between the two coders, served to enhance the robustness of the findings. Pseudonyms were used throughout the paper to present the results.

RESULTS

Sequential analysis results

Descriptive statistics

A total of 2586 talk moves were collected, among which there were 1373 teacher talk moves and 1213 student talk moves. The bar charts that show the frequencies of enacted talk moves are illustrated in Figure 2. For teacher talk moves, the most frequent one is *Follow up* ($n=407$, 30%), followed by *Pragmatic* ($n=309$, 23%) and *Direct answers* ($n=220$, 16%). The three most frequent student talk moves are *Simple answer* ($n=352$, 29%), *Explanation with supporting evidence* ($n=267$, 22%) and *Question for deeper understanding* ($n=225$, 19%).

Association rule mining findings

For sequential analysis, we focused on patterns showing transition from student to teacher talk moves. The results of association rule mining were categorized based on the types of responsiveness of teacher talk moves, that is, productive, neutral and unproductive responsiveness (see Tables 3–5).

For productive responsiveness, a total of 10 patterns were extracted. It can be observed that participants generally enacted responsive teaching to different student talk moves. One pattern was discovered for off-topic student talk: *Off-topic* (S) → *Attending to specific student* (T) (Lift = 2.93, $Q=0.51$). When students were silent, there was a low chance but high association with *Follow-up* (T) + *Connect* (T) (Confidence = 0.08, Lift = 1.25, $Q=0.41$). When students were on topic, participants were able to actively practice productive responsiveness. For example, *Explanation with partial understanding* (S) → *Follow-up* (T) + *Connect* (T)

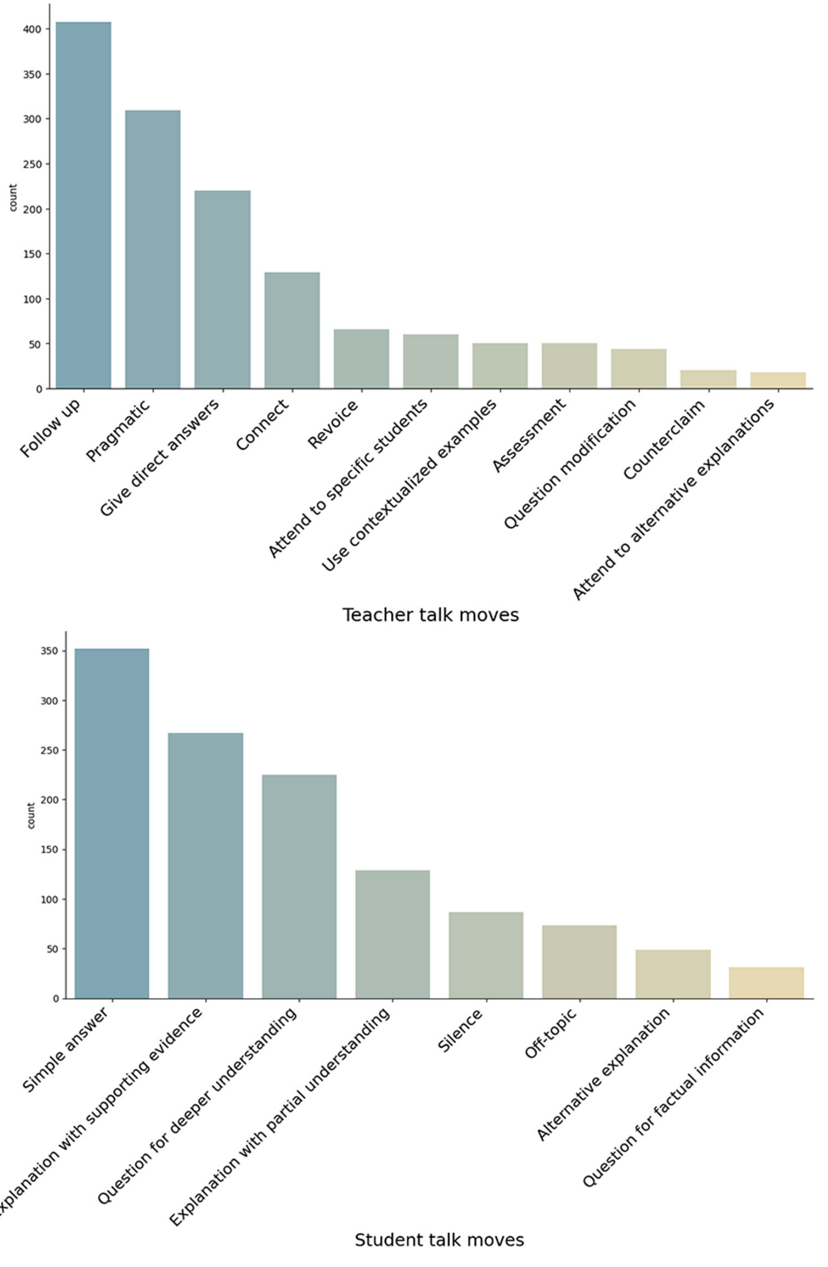

FIGURE 2 Frequency of teacher and student talk moves.

(Lift = 1.23, *Q* = 0.91) has a strong and positive association. No patterns of student questions and productive talk moves were identified.

Three patterns were revealed for teaching practices with neutral responsiveness. For example, there is a high confidence and strong association between *Silence* (S) + *Off-topic* (S) and *Pragmatic* (T) (Confidence = 0.86, Lift = 1.48, *Q* = 0.51).

Five patterns were found for unproductive, responsive teaching. One interesting pattern is *Alternative explanation* (S) → *Assessment* (T) (Lift = 1.59, *Q* = 0.83), indicating a tendency for participants to correct alternative explanations. There is also a strong association between

TABLE 3 Patterns of teacher talk moves with productive responsiveness.

Patterns (from virtual students to PSTs)	Confidence	Lift	Yule's *Q*
Off-topic → Attending to specific student	0.14	2.93	0.51
Silence → Follow up + Connect	0.08	1.25	0.41
Simple answer → Connect + Attend to specific student	0.10	2.34	0.87
Explanation with evidence + Question seeking deeper understanding → Counterclaim	0.08	1.77	0.69
Explanation with evidence → Connect + Revoice	0.17	1.26	0.53
Explanation with partial understanding → Use contextualized example	0.05	1.24	0.80
Explanation with partial understanding → Follow-up + Connect	0.14	1.23	0.92
Explanation with partial understanding + Simple answer → Attend to alternative explanation	0.17	4.19	0.71
Alternative explanation → Question modification	0.24	2.63	0.79
Alternative explanation → Follow-up + Use contextualized example	0.14	2.61	0.68

TABLE 4 Patterns of teacher talk moves with neutral responsiveness.

Patterns (from virtual students to PSTs)	Confidence	Lift	Yule's *Q*
Silence + Off-topic → Pragmatic	0.86	1.48	0.51
Off topic → Pragmatic	0.62	3.01	0.53
Explanation with partial understanding → Pragmatic	0.28	1.58	0.74

TABLE 5 Patterns of teacher talk moves with unproductive responsiveness.

Patterns (from virtual students to PSTs)	Confidence	Lift	Yule's *Q*
Alternative explanation → Direct answer	0.26	1.43	0.47
Alternative explanation → Assessment	0.17	1.59	0.83
Question for deeper understanding → Direct answer	0.50	1.68	0.65
Questions for factual information → Direct answer	0.28	1.51	0.53
Silence → Pragmatic + Question modification	0.08	2.59	0.41

questions and *Direct answer*, such as *Question for deeper understanding* (S) → *Direct answer* (T) (Lift = 1.68, Q = 0.65).

Markov Chain transition matrix

The Markov Chain transition matrix further validated the results from association rule mining and provided a holistic view of the transitions (see the diagram in Figure 3). At the alpha level of 0.05, we discovered 12 significant transitions from student to teacher talk moves. For productive responsive teaching, *Follow-up* was most probably the adopted strategy to address *Short answer* (pr = 0.38), *Explanation with evidence* (pr = 0.42) and *Explanation with partial understanding* (pr = 0.39).

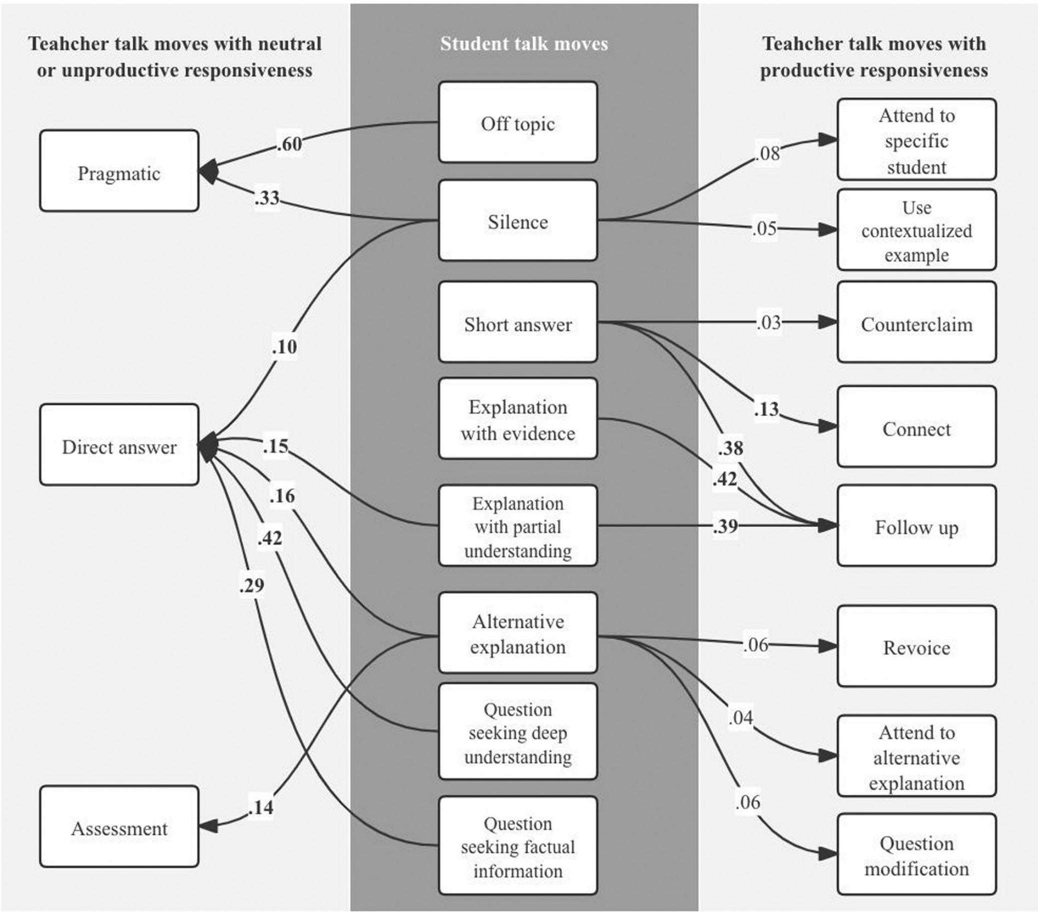

FIGURE 3 Markov Chain transition diagram.

For neutral responsive teaching, PSTs mostly used *Pragmatic* in response to *Off topic* and *Silence* (pr = 0.60, pr = 0.33). For unproductive responsive teaching, *Direct answer* was most frequently adopted to address questions (eg, *Question seeking deep understanding*, pr = 0.42), *Silence* (pr = 0.10) and low-understanding responses (eg, *Explanation with partial understanding*, pr = 0.15). Lastly, there was a significant probability for PSTs to initiate *Assessment* for *Alternative explanation* (pr = 0.14). All the other transitions had low transition probabilities (pr < 0.10) and were not significant.

Emerging themes in AI-powered teaching practice

To answer the second research question governing the affordances and challenges of AI-powered virtual simulation for PSTs to practice responsive teaching, three salient themes emerged from the qualitative thematic analysis: (1) orchestrating discussion by leveraging the design features of AI-supported simulation, (2) iterative rehearsals through naturalistic and contextualized interactions and (3) exploring realism and boundaries in AI-powered virtual students. The findings indicated the potential of AI-supported virtual simulation in supporting PSTs' practice of responsive teaching skills and underscored the need for PSTs to engage in well-designed pedagogical practices with adaptive and in situ support.

Orchestrating discussion by leveraging the design features of AI-supported simulation

PSTs were observed actively leveraging the correspondence gadgets to orchestrate discussion, altering between addressing the whole class and individual students. They built on individual students' ideas and brought the conversation forward by asking follow-up questions (using talk moves such as *Follow-up*), prompting students to explain, justify and connect their thoughts, such as '*What do you mean they got denser?*' Alternatively, they upgraded the exchange with one student to a whole-class discussion and invited more students into the conversation (using talk move *Connect*). For example, teachers asked, '*Robert mentioned the structure of the fungi. Are there other structures that are important such as the germ tube?*' These instances reflected how PSTs were actively orchestrating a discussion in a virtual classroom using productive talk moves, corroborating the findings in the quantitative analysis.

All responses from AI-powered virtual students were recorded in the chat panel, facilitating consensus building by enabling PSTs to track individual students' contributions. PSTs were observed, identifying the varying understanding levels among students as they composed the responses. For example, Cara reasoned when developing a response to a student with low understanding, '(thinking aloud) *Ok. So we want to help Nick understand that, things we can't see them, until something happens. And then the molecules change and we can see it. Okay, so maybe we can think of a different example, like, ice*?' As PSTs interacted with virtual students in real time, they also noticed those students who were less active and tried to engage them in classroom discussion by directly addressing them. Here is an example from Rebecca's class,

> Rebecca (T): (Thinking aloud) *I don't think I've heard from Robert, let's talk to Robert*. (Talking directly to Robert) *Do you know anything about enzymes?*
>
> Robert (S): *They break down organic material into simple sugars*.

These interactions provide a glimpse into the dynamics of teacher–student interaction in AI-supported virtual simulation. PSTs were actively engaging with the simulation, adapting and employing various talk moves to stimulate discussion and connect with students at different levels of understanding.

Iterative rehearsals through naturalistic and contextualized interactions

Supporting our quantitative findings, conversations afforded by AI-powered virtual students, as observed, engaged PSTs in proactively interpreting and responding to student thinking as well as facilitating in situ reflection, which are core practices conveying a responsive teaching approach. Participants perceived the conversation with AI-powered virtual students as authentic, and providing the opportunities to engage in human-like exchanges and learn through practice. For example, Camila shared in the interview, '*It does a good job of showing like, how the students like. I think it's fascinating. It could be used for this very reason to help teachers understand how to respond to students, and how to facilitate a group…a group discussion*'.

With virtual students' real-time responses, PSTs were observed actively engaging in the cognitive activities of both interpretation (analysing student discourse) and decision-making (deciding how to respond). PSTs paid close attention to the language used, identifying what the virtual students knew and did not know. Simultaneously, they reasoned about how to respond and adapted their responses to the students' current understanding. For example, the facilitator observed Abigail to be adaptive and analytical, '*She constantly analyzes the discourse and practices teaching. She adapted to students' own words and understanding.*

She adjusted strategies to use "Yes/No" questions but would follow up with higher-order thinking questioning (observational notes)'. After students responded, the teachers reflected on the impact of their pedagogical decisions and decided if it was necessary to modify their teaching moves. For example, Monica pondered over the exchanges, saying, '*I want to be a little more specific, because I think I already asked a question, and maybe whatever Thomas was supposed to say would probably confuse them*'.

Despite the real-time, naturalistic conversations with virtual students, PSTs reported a lack of epistemic and pedagogical resources to analyse student thinking or make instant decisions, thereby struggling to practice responsive talk moves. For example, Anna interpreted the students' idea, saying, '*I mean, technically he's right. Like steam is not very dense at all, and like I see what he's saying. [But] I don't know how to respond to it*'. Additionally, some PSTs reported instances where students' responses, although natural, lacked 'productive beginnings' for them to build on, especially when they were silent or gave short answers. As Gina shared, '*I think like, a few times, the students just didn't give back, didn't return something that I could continue with*'. This situation could become increasingly challenging when students repeatedly remain silent to teachers' questions, leading them to answer their own questions. These reflections corroborated the finding of quantitative sequential analysis that PSTs tended to employ neutral or unproductive talk moves (*Pragmatic* and *Direct answer*) to address student silence and off-topic comments in the simulation.

Exploring realism and boundaries in AI-powered virtual students

PSTs found teaching AI-powered virtual students similar to teaching real-world students, and reported a perception of virtual students as realistic. For example, Mary characterized the students as possessing distinct personalities akin to real people, stating, '*John is like a … very much a go getter. And he seems to know, like a lot of what he's talking about*'. This sense of realism prompted PSTs to practice teaching with heightened engagement. Alice noted she learned to value every student's contribution, saying, '*I learned that … it is like super important to have everybody talk, because everybody has their own ideas, you can use all of those ideas to kind of help all of them work together in a sense*'.

Nevertheless, some PSTs reported difficulties in facilitating the discussion in ways that are personally relevant to the virtual students. In particular, they found it difficult to draw upon students' 'prior experience' and make disciplinary connections. For instance, while introducing the concept of gas laws, Camila asked whether virtual students had blown up a balloon, and students said 'no'. Frustrated, she remarked, '*That's boring. In any real classroom environment, people would have been sitting there saying that they had blown up balloons*'. In relation to this, participants expressed their desire to build personal relationships with the students. They believed that if they knew students better, they could ask more targeted questions and establish better connections. As Helen said, '*It's [teaching virtual students] harder than being in a real classroom. In a real classroom where you're engaged and you're looking at them, you remember who said what, and you're really face to face with them*'.

DISCUSSION

Preparing PSTs to enact responsive teaching is an important goal for teacher preparation. This study explored how PSTs experienced teaching AI-powered students in a virtual simulation. Quantitative sequential analysis of the talk moves revealed that PSTs generally can enact responsive talk moves, though unproductive talk moves are persistent in their teaching. Qualitative thematic analysis results based on the participatory observation and interview data corroborated the sequential analysis findings and offered further insights. We identified that AI-supported virtual simulation embodies both opportunities and challenges for PSTs to practice and improve their responsive teaching skills. The AI-supported simulation, integrated with interactive design features and virtual students, affords iterative and contextualized opportunities for PSTs to practice responsive teaching talk moves. The interactivity, on the other hand, requires teachers to analyse student discourse and respond in real time, thereby posing challenges to them.

PSTs' discourse patterns in AI-supported virtual simulation

The findings highlight the tension between pursuing student ideas and knowledge dissemination during PSTs' practice of teaching with AI-powered virtual students. *Follow-up* was the most enacted talk move across classes, indicating PSTs' constant effort in prompting students to elaborate on their ideas and practices that can encourage student participation and enhance the quality of their discussion (Colley & Windschitl, 2016; Kang et al., 2014). However, *Direct answer* was one of the most practiced talk moves following *Pragmatic*. It was a prevalent, yet not responsive, talk move that PSTs employed in response to nearly all types of student talk moves. This finding supports previous studies suggesting that PSTs should increase their awareness of alternative responsive talk moves and enact the responsive talk moves with certain fluency (Mercer & Littleton, 2007; Oliveira, 2010; Pimentel & McNeill, 2013). It also underscores PSTs' struggles to shift away from the discourse patterns in a traditional, teacher-centred classroom, where teaching is framed towards delivering correct answers or algorithms and prioritizing well-established knowledge over student thinking (Hutchison & Hammer, 2010; Kaya et al., 2023; Russ et al., 2009).

Meanwhile, there is an inequality in PSTs' enactment of responsive talk moves. While PSTs were able to leverage productive talk moves, they predominantly employed *Follow-up* and *Connect*. We observed fewer *Counterclaim* or *Attend to alternative explanations* in the sessions. This observation provides an avenue for further exploration and development, suggesting that with additional support and guidance, PSTs can expand their repertoire of productive talk moves, contributing to a more comprehensive and inclusive learning environment. Further, this finding indicates that there is a hierarchy in talk moves, with some being easier to acquire and practice (Michaels & O'Connor, 2015). Prior studies found that teachers, both novices and experts, have difficulties in practicing complex, advanced talk moves such as *Counterclaim* (Teo, 2016; Tytler & Aranda, 2015). Acquiring a wide variety of talk moves, both basic and advanced, is essential for PSTs to effectively scaffold student talk in diverse teaching scenarios (Colley & Windschitl, 2016). The finding indicated that more targeted efforts should be made to improve their ability to enact more advanced talk moves.

A salient trend is that PSTs' responsive teaching moves were more productive when virtual students were ‘on the right track’ or demonstrated a desirable understanding of the content. However, when students were silent, or expressed unproductive resources, we found that PSTs were inclined to deliver facts or assess student thinking. The findings suggest that it is more challenging for PSTs to be responsive to students' thinking when the answers are ‘unexpected’ or do not conform to the established ways of knowing (Rosebery et al., 2016). With a limited teaching repertoire, they would swiftly shift to a traditional teaching approach, as has been documented in face-to-face classrooms (Grinath & Southerland, 2019). This finding implies that PSTs should be prepared not only for common, easy-to-tackle scenarios but also for ‘unexpected’ or challenging ones, as these situations more closely reflect the complexity of real-world teaching.

Supporting previous studies (Aguiar et al., 2010; Eshach et al., 2014), we found that PSTs most likely framed students' questions as a request for information and responded directly to those questions. In science and mathematics classrooms, student questions are crucial for meaningful learning because questions focus students' attention on disciplinary thinking while articulating their current understanding of the concepts (Chin & Osborne, 2008). To foster a student-centred and inquiry-based learning environment, teachers are expected to refrain from immediately answering student-generated questions, and instead, support them in constructing and refining the answers (Furtak, 2006; NGSS Lead States, 2013). Despite observed productive talk moves, the current study reveals that it is challenging for PSTs to refrain from providing answers.

Affordances and challenges of AI-supported virtual simulation

Thematic analysis provides valuable insights into the potential of AI-supported virtual simulation to support PSTs' orchestration of classroom discussion, an important element in responsive teaching that supports students' science and mathematical thinking (Jacobs & Empson, 2016). The interactive design features of AI-supported virtual simulation, such as correspondence boxes, appeared to support PSTs' active engagement and participation. PSTs were observed leveraging these features to orchestrate discussion and build consensus among the students. They were encouraged to attend to individual students' contributions and create equitable learning opportunities by scaffolding students' understanding and involving those students who are less active. Those responsive talk moves position students as active sense-makers rather than passive information recipients, promoting an equitable and inclusive environment for science and mathematics learning (Miller et al., 2018).

Supported by the naturalistic and contextualized interactions with AI-powered virtual students, PSTs benefitted from the iterative opportunities to practice teaching skills and learn from these experiences. Virtual students' responses appeared to stimulate PSTs' cognitive activities of interpretation, decision-making and reflection, which are key steps in practicing responsive teaching in science and mathematics (Dyer & Sherin, 2016; Levin et al., 2012). These findings corroborate prior research suggesting that simulation-based learning supports teachers' enactment of decomposed teaching skills and reflective practices (Dai et al., 2024; Ledger et al., 2022; Mikeska et al., 2023) and empowers them to attend to student thinking (Ke et al., 2020; Zhang et al., 2024). Moreover, the findings contribute to the research discourse that the incorporation of AI-powered virtual students increased interactivity in teaching, prompting PSTs to respond and adapt to diverse teaching scenarios in real time. Despite the promising findings, the study also revealed challenges of enacting responsive talk moves due to limited pedagogical and epistemic resources. This finding echoes prior research on the complexities of implementing responsive teaching in practice (Osborne et al., 2013; Sedova et al., 2014) and suggests the need for designing on-site, structural learning support that assists PSTs in attending, interpreting and responding to different forms of student participation in a productive and responsive way (Braaten & Sheth, 2017; Levin et al., 2009).

Related to the natural conversations, PSTs found teaching AI-powered virtual students similar to teaching real-world students. This sense of authenticity and realism heightened their engagement in interacting with students. This finding supports the previous report that positive learning experiences depend on participants' perceived authenticity and realism (Theelen et al., 2019). On the other hand, participants also reported struggles in teaching virtual students in a responsive way due to difficulties in eliciting their personal experiences and building personal relationships. Knowing the students and building student-teacher relationships underlie teachers' decisions to enact responsive talk moves (Jacobs &

Empson, 2016). The findings underscore the importance of enhancing the realism of virtual students to better support PSTs' learning experiences.

Implications

This study provided important implications for teacher educators, researchers and instructional designers regarding the design and implementation of AI-supported virtual simulations for practicing responsive math and science teaching.

First, the study identified both productive talk moves enacted by PSTs in this simulation and irregularities and inequalities in the responsive teaching talk moves the PSTs enacted. To further support PSTs' teaching repertoire, future studies could consider designing teaching scenarios for practicing advanced responsive talk moves. Second, PSTs, particularly those without prior teaching experience, experienced great challenges in orchestrating responsive discussions. We call for the need for future studies to design learning modules that adapt to PSTs' prior experience. For example, teachers can start practicing teaching with one virtual student and then move towards orchestrating discussions with multiple students. Alternatively, the simulation could allow PSTs to start by practicing individual talk moves and proceed towards using combinations or sequences of different moves. Third, while teachers can engage in real-time pedagogical reasoning and decision-making in such simulations, adaptive learning support should be designed and implemented to help them navigate challenges. For example, different instructional supports, such as adaptive feedback and prompts, can be provided. Teacher educators can also prompt reflexive support by having PSTs watch and reflect on their own teaching problem-solving practices and make their responsive efforts the substance of in-class discussions. Fourth, the study demonstrates the feasibility of leveraging AI-supported simulation for responsive teaching practice. Interaction features (eg, chat panel) and the integration of AI-based virtual students facilitated PSTs' active participation. The use of an open-source platform would potentially enhance the scalability of AI-supported, simulation-based learning. Lastly, realism and authenticity are essential to PSTs' engagement. We suggest future studies train the AI model with a larger and multidimensional dataset, enabling virtual students to engage in disciplinary practices with different knowledge representations.

LIMITATIONS

This study has several limitations. First, the current study has a relatively small sample size ($n = 24$). Although we used a concurrent mixed-methods research design to corroborate the findings, the study findings should be interpreted with caution. Future studies should replicate the investigation with a larger group of PSTs. Second, prior research suggested that duration of the session implementation can impact teachers' learning outcomes (Dai et al., 2023). The participants in the current study participated in the virtual teaching simulation for two hours. Although a 2-hour session meets the purposes of the current study, we recommend future studies consider extending the implementation duration to further examine the impact of AI-supported teaching simulation.

CONCLUSIONS

This study explored PSTs' responsive teaching experiences in an AI-supported virtual simulation. We found that PSTs enacted target responsive talk moves in the designed scenarios in AI-supported virtual simulation. In general, purposefully designed AI-supported virtual simulation engaged PSTs in authentic and real-time interaction with virtual students, prompting them to attend to, analyse and respond to student responses and be adaptive and reflective. However, some participants also experienced challenges in shifting from a teacher-centred teaching pattern due to limited teaching repertoire. The results highlight the need to provide in situ and adaptive support to PSTs to assist them in navigating challenges. Future studies should continue to explore how the learning experiences in AI-supported virtual simulation can be designed to optimize PSTs' learning and practice of responsive teaching.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

The participants of this study did not give written consent for their data to be shared publicly, so original data are not available due to the sensitive nature of the research. Anonymous quantitative and qualitative analysis results can be made available upon request.

ETHICS STATEMENT

This study received approval from the university IRB (human subject protection) and was conducted in accordance with the ethical guidelines.

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SUPPORTING INFORMATION

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

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