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Developing and evaluating the fidelity of virtual reality-artificial intelligence (VR-AI) environment for situated learning

April Tan[1,2], Michael C. Dorneich[1]* and Elena Cotos[2]

[1]Department of Industrial and Manufacturing Systems Engineering, Iowa State University, Ames, IA, United States, [2]Department of English, Iowa State University, Ames, IA, United States

Introduction: Socialization is crucial for facilitating disciplinary enculturation, yet traditional classroom instruction often lacks authentic socialization opportunities, limiting students' exposure to their disciplinary communities. To address this gap, this study develops an immersive Virtual Reality-Artificial Intelligence (VR-AI) environment that simulates academic conference poster sessions. Learners interact with AI-driven agents, engaging in discussions and receiving real-time feedback on research communication. This study focuses on developing, operationalizing, and evaluating the fidelity of the VR-AI environment across four key dimensions: physical, functional, psychological, and social fidelity.

Methods: Twenty participants tested the environment, completing two learning tasks: engaging with poster presenters and reflecting with a major professor. Fidelity was assessed using mixed methods, including presence questionnaires, workload assessments, behavioral observations, and semi-structured interviews.

Results: Findings indicate high physical and functional fidelity, with participants describing the environment as immersive and reflective of real-world academic settings. Psychological fidelity was also well represented, as learners engaged in cognitively demanding research discussions and rhetorical reflection. However, social fidelity remained a challenge, as AI agents struggled with conversational turn-taking and response length, reducing the authenticity of academic exchanges.

Discussion: These findings highlight the potential of VR-AI environments for disciplinary socialization while underscoring the need for refined AI-driven interaction designs to support more fluid, reciprocal dialogue.

1 Introduction

This study aims to operationalize, develop, and evaluate a Virtual Reality-Artificial Intelligence (VR-AI) learning environment to aid graduate students in developing the socio-rhetorical knowledge of their discipline. Developing socio-rhetorical knowledge is crucial in mastering research genres across an academic discipline. Genres can be defined as "socially recognized ways of using language" (Hyland, 2007, p. 149) that emerge to fulfill recurring communicative needs. These genres may include research articles, conference presentations, book reviews, and poster presentations, amongst many others.

Genre knowledge involves understanding the expectations and confirming with the conventions of the target disciplinary community. As identified by Tardy et al. (2020), four key domains are necessary for genre acquisition: formal knowledge (structural features and conventions), rhetorical knowledge (purpose and audience expectations), process knowledge (creation and distribution steps), and subject-matter knowledge (disciplinary content). This study focuses on rhetorical knowledge to help novice members of the disciplinary community better understand and adapt to the communicative situations and expectations of research-related genres. Rhetorical knowledge must occupy a more prominent place in technology-assisted academic writing in both research and pedagogy; otherwise, theoretically imbalanced instruction will expose novice writers to an overemphasis on subject-matter knowledge at the expense of rhetorical knowledge, even though each is necessary and neither is sufficient on its own (Tardy, 2005). Arguably, developing rhetorical knowledge is a complex process that requires novice scholars' socialization into their disciplinary communities (Casanave, 2002; Johns and Swales, 2002). Successful rhetorical knowledge development involves being socialized into the socio-disciplinary expectations of the discourse community and the ability to make appropriate rhetorical choices in communication based on those expectations (Hyland, 2018). Because the primary task of a researcher is to convince other researchers within the disciplinary community of their scientific contribution, rhetorical knowledge is paramount. As rhetorical knowledge can be successfully acquired through a process of socialization, early and frequent exposure to the socio-rhetorical practices of a disciplinary community is crucial (Kobayashi et al., 2017; Tardy et al., 2020).

Rhetorical knowledge is a type of implicit insider knowledge that cannot be acquired by novice scholars like graduate students only in formal course settings (Ahn and Lee, 2016; Lee and Park, 2020; Yang, 2006). While classroom instruction creates conditions for *learning about* their disciplinary community, it is limited in that students cannot *participate in* the actual practices of the community itself. Socialization into the community can only be achieved through interactions with core members who have a stronger, more proficient grasp of the conventions and practices of their discipline (Duff, 2010). However, research has shown that many graduate students often lack access to their disciplinary communities (Duff, 2007; Haneda, 2006) and that this lack of access is detrimental to their overall proficiency of producing research genres (Tardy et al., 2020; Zappa-Hollman, 2007). This gap underscores the need for innovative pedagogical approaches that can bridge the divide between classroom learning and real-world academic practice.

Emerging technologies like Virtual Reality (VR) and Artificial Intelligence (AI) hold potential in addressing this need, particularly in integrating the two to create a situated learning environment. Situated learning theory posits that meaningful learning can only take place if it is embedded in the social and physical context within which it will be used (Brown et al., 1989). According to instructional technologists, situated learning environments need to provide authentic context, authentic activities, access to expert performances, multiple perspectives and guidance, collaborative knowledge construction, and reflection to articulate tacit knowledge (Herrington and Oliver, 2000). The technological affordances of VR and AI can be used to create meaningful

situation learning environments. VR allows designers to immerse learners in simulated settings that replicate real-world disciplinary communities and practices, while AI-driven generative agents can emulate the communication of expert community members' knowledge, values, and interactional patterns. For instance, a VR-AI environment of an academic conference poster session could allow learners to present research to other scholars, watch more experienced presenters present, respond to audience critiques, and interact with scholars from a wide range of fields and perspectives. Through tailored activities, designers can scaffold collaborative knowledge construction (e.g., negotiating feedback with other researchers) and prompt reflection on tacit norms, allowing leaners to exercise their socio-rhetorical understanding in real-time.

Guidelines on how to develop situated learning environments are scarce, particularly within the realm of commercial-grade VR and Generative AI. A key challenge in developing situated learning environments lies in aligning learning objectives, theoretical underpinnings, and technological affordances to ensure its design supports the intended pedagogical outcome. Recent systematic reviews of the use of VR technologies in higher education found a rise in its adoption but have also noted a significant lack of explicit pedagogical frameworks in the development and use of these environments (Chen et al., 2024; Radianti et al., 2020), resulting in poorly designed instructional activities and ambiguity in learning outcomes. Similarly, recent systematic reviews of AI in higher education have called for adopting educational theories in the use of AI technologies (Chen et al., 2020; Ouyang et al., 2022; Zawacki-Richter et al., 2019). While generative AI agents like GPTs can simulate human-like interactions, their pedagogical effectiveness hinges on training protocols that embed learning theories and objectives. Additionally, guidelines on evaluating a situated learning environment are also limited, leading to the adoption of environments without sufficient testing and validation. In order for a situated learning environment to be successful, it is necessary first to establish whether it captures fundamental features of the actual task and environment, and whether it elicits realistic behavior. The design of these features demands careful attention to *fidelity*—the degree to which simulations replicate real-world systems (Harris et al., 2020). While many types of fidelities exist, this study focuses on physical (visual and sensory realism), functional (realistic use and behavior of objects), psychological (replication of cognitive demands), and social fidelity (realism of interpersonal interactions), as these aspects are particularly important for pedagogical effectiveness. For training and learning purposes, the environment needs to be only as "real" as required to achieve the desired learning outcomes. Without intentional alignment of pedagogical goals, fidelity dimensions, and technological capabilities, simulations risk fostering superficial engagement.

This study aims to address these gaps by developing, operationalizing, and evaluating a genre-based VR-AI environment that simulates a conference poster session, a context chosen for its density of socialization activities, including real-time feedback exchanges, interactive negotiations, and models of expert performances (Tan et al., 2023a). The intended learning outcome is to enhance learners' social and rhetorical understanding of their disciplinary communities. The research objectives of this study are as follows:

1. *Development*: To describe the development of the learning environment grounded in learning theories, creating a design rationale that aligns VR/AI affordances with socio-rhetorical learning goals.
2. *Operationalization:* To provide directions for training and integrating GPT agents as pedagogical proxies, using discipline-specific corpora and rhetorical schemas to encode authentic interactional patterns characteristic of research communication.
3. *Evaluation:* To test and validate the learning environment's physical, psychological, and interactional fidelity as a poster session for pedagogical use.

As scholarship in academic research communication continues to evolve in the digital age, this study contributes to the broader discourse on addressing the challenges of academic socialization while also providing a framework for the design and evaluation of VR-AI learning environments that can be adapted to other educational contexts.

2 Related works

This study develops and evaluates a VR-AI learning environment aimed at fostering socio-rhetorical knowledge, a key domain of genre knowledge. This section examines genre theory to understand the role of rhetorical knowledge and how it is developed through social interactions. This study draws from research on situated learning theory and genre theory (Swales, 1990), leveraging its process of learning through which socio-rhetorical knowledge can be developed. Building on this foundation, the study explores the affordances of VR and AI in creating a situated learning environment. Finally, this study reviews fidelity as an evaluative framework to test and validate the environment on its pedagogical usefulness. By grounding learning theories with meaningful integration of emerging technologies, this work aims to serve as a valuable guideline for the design and evaluation of VR and AI learning environments.

2.1 Genre knowledge and genre-based pedagogies

At its core, genres can be defined as "socially recognized ways of using language" (Hyland, 2007, p. 149) that emerge to fulfill recurring communicative needs. Acquiring knowledge of a genre is a complex and multilayered process as members within these communities need to know not just the preferred forms of a genre but how and when a genre can be used to further a community's goals, the common practices and values of the genre users, the identity taken on in using the genre, the subject-matter of their discipline, and how to exploit the genre for their own agendas (Tardy et al., 2020). Tardy et al. (2020) provide a comprehensive framework detailing the four crucial domains for genre knowledge acquisition:

- *Formal knowledge:* Understanding of the structural features, conventions, and stylistic norms of a genre (e.g., organization, formatting, language use)
- *Rhetorical knowledge:* Understanding of genre's purpose, audience expectations, and strategies to help achieve its goals
- *Process knowledge:* Understanding of steps involved in creating, distributing, and using the genre (e.g., drafting, revising, peer review process, publishing process)
- *Subject-matter knowledge:* Understanding of disciplinary content

This study focuses on rhetorical knowledge for several critical reasons. Firstly, despite its importance, rhetorical knowledge is often marginalized in formal curricula (Tardy, 2005; Zhang and Zhang, 2021). Rhetorical knowledge is often assumed to develop implicitly through exposure to academic discourse, leading educators to prioritize subject-matter knowledge and technical skills over the nuanced teaching of rhetorical competence. Secondly, while most genre-based approaches in the classrooms aim to raise rhetorical awareness, these approaches still fall short in providing authentic context and opportunities for practice. Due to the nature of formal classroom education, classroom activities are often decontextualized, with assignments focused on producing texts for the instructor rather than engaging with real-world audiences or purposes (Devitt et al., 2003; Hyland, 2007). For instance, while popular tasks like analyzing model texts or practicing rhetorical moves (i.e., communicative goals) can raise awareness of genre conventions and do indeed contribute to developing rhetorical knowledge, they still fail to immerse students in the dynamic social contexts where genres are actively negotiated and used (Freedman and Medway, 2003; Worden, 2018). Consequently, genre-based practitioners have advocated for more situated and authentic practices that integrate rhetorical instruction with meaningful, context-rich activities to better socialize learners (Hyland, 2022; Tardy, 2005). These limitations highlight the need for pedagogical approaches that immerse learners in authentic social contexts—making situated learning an ideal complement.

2.2 Situated learning for rhetorical knowledge acquisition

Situated learning theory offers a valuable pedagogical framework for addressing the limitations of genre-based pedagogy by suggesting how learners can develop rhetorical knowledge through meaningful participation in communities of practice. Defined as a process where individuals acquire knowledge and skills by engaging in authentic activities within real-life contexts (Lave and Wenger, 1991), situated learning emphasizes participation over abstraction. Derived from Sociocultural Theory (Vygotsky, 1978), situated learning builds on the idea that learning occurs through social interaction and mediation, with expert members scaffolding newcomers' understanding of community norms. It also extends sociocultural theory by introducing the concept of legitimate peripheral participation, which describes how novices gradually transition from peripheral observers to full participants in a community of practice as they gain expertise and integrate into the sociocultural practices of the group.

This theory is particularly instructive for rhetorical knowledge acquisition because it emphasizes authentic engagement within disciplinary communities, which are essentially communities of practice. Such engagement is an essential component typically missing from traditional classrooms (Kobayashi et al., 2017; Tardy et al., 2020; Zappa-Hollman and Duff, 2015). Through repeated interactions with experts and meaningful tasks–such as presenting at simulated conferences–novices would be able to internalize the socio-rhetorical logic underpinning disciplinary communication. Herrington and Oliver (2000) identify nine essential elements for creating effective situated learning environments:

1. Provide authentic contexts that reflect the way knowledge will be used in real life
2. Provide authentic activities
3. Provide access to expert performances for the modeling of processes
4. Provide multiple roles and perspectives
5. Support collaborative construction of knowledge
6. Promote reflection to enable abstractions to be formed
7. Promote articulation to enable tacit knowledge to be made explicit
8. Provide coaching and scaffolding by the teacher at critical times
9. Provide authentic assessment of learning within the tasks.

However, traditional classroom activities often fail to meet these criteria, as creating situated learning activities is very difficult in the formal classroom setting (Ahn and Lee, 2016; Lee and Park, 2020; Yang, 2006). Emerging technologies like VR and AI offer promising avenues to address these challenges by simulating immersive environments where learners can engage with realistic rhetorical situations while receiving scaffolded feedback akin to expert guidance within communities of practice. By bridging this gap between theory and application, situated learning complements genre-based pedagogy effectively while addressing its shortcomings in teaching rhetorical knowledge in close to authentic ways.

2.3 VR and AI affordances for creating situated learning environments

2.3.1 VR affordances

The growing field of VR has spurred extensive discussions on its affordances for learning, particularly in creating immersive and interactive environments (Burdea and Coiffet, 2003; Slater et al., 2022; Steffen et al., 2019). Kaplan-Rakowski and Gruber (2019) define VR environments (VREs) as "computer-generated 360° virtual spaces that can be perceived as being spatially realistic due to the high immersion afforded by a head-mounted device" (p. 552). Immersion, a key feature of VR, refers to the subjective impression of being fully engaged in a comprehensive, realistic experience (Dede, 2009). Drawing on Steffen et al.'s (2019) framework, VR technology enables immersive learning experiences by creating, recreating, enhancing, or diminishing aspects of physical reality in simulated environments. These

affordances align with Herrington and Oliver (2000) nine essential elements of situated learning environments by allowing instructors to create authentic contexts and activities that mirror authentic contexts and practices, providing access to expert performances through modeled behaviors and enabling learners to assume multiple roles and perspectives. For example, VR can simulate academic poster sessions where learners present research and interact with AI agents representing members of their target disciplinary community. Such immersive tasks support collaborative knowledge construction, foster reflection on rhetorical strategies, and promote articulation of tacit knowledge in ways that traditional classrooms cannot.

Despite their promising potential, systematic reviews have consistently highlighted that most VR-based educational interventions focused on the technological capabilities of VR, while only a few provided theoretical models (Chen et al., 2024; Fowler, 2015; Pellas et al., 2021; Radianti et al., 2020) or explicitly aligned VR affordances informing the design of a VRE (Fromm et al., 2024; McGowin et al., 2021). The lack of theoretical grounding can inadvertently lead to inconsistent learning outcomes (Radianti et al., 2020). Poorly designed instructional activities in immersive environments can reduce their effectiveness in achieving pedagogical goals (Chen et al., 2024). Theoretically informed instructional designs are needed to maximize the educational potential of VR applications (Pellas et al., 2021). These insights underscore the importance of aligning VR affordances with learning theories to ensure meaningful and effective learning experiences.

2.3.2 AI affordances

AI offers significant affordances in higher education, particularly in learning, teaching, assessment, and administration (Chiu et al., 2023; Zawacki-Richter et al., 2019). Empirical research has shown that, in some instances, AI can enhance online instruction and learning quality through high-accuracy prediction, personalized recommendations, and increased engagement and participation (Ouyang et al., 2022). In the context of this study, it could be used to create authentic communities of practice by simulating dynamic interactions with mentors and other community members. Through the use of GPT models, AI agents can be trained to embody the rhetorical knowledge, conventions, and identities unique to specific disciplinary communities, enabling learners to engage with these agents as believable community members. These affordances also align well with Herrington and Oliver (2000) framework for situated learning environments. AI agents can act as mentors or peers, offering tailored feedback, modeling disciplinary norms, and facilitating collaborative tasks. AI can also support collaborative knowledge construction through interactive dialogue with agents and promote reflection and articulation of research content by enabling learners to receive immediate feedback on their communication strategies. Additionally, AI systems can be designed to provide scaffolding at critical moments by adapting responses to learners' needs and offering formative assessments embedded within tasks. By aligning these affordances with situated learning principles, AI can serve as a powerful tool for fostering rhetorical knowledge acquisition and preparing learners for effective participation in their disciplinary communities.

Despite these promising affordances, systematic reviews have highlighted a critical gap in aligning AI applications with robust educational theories. For example, Ouyang et al. (2022) found that while AI applications in higher education have demonstrated potential for improving academic performance and engagement, their effectiveness is often undermined by a lack of integration with learning theories or long-term empirical validation. Similarly, Chen et al. (2020) emphasized the need for theoretically grounded designs to maximize the pedagogical impact of AI systems. Addressing these challenges requires not only integrating AI with established learning theories but also ensuring that AI fosters meaningful and context-rich interactions. These reviews recommend incorporating authentic characteristics and real-time process data to enhance agent accuracy, which is important if using it as a tutoring system. Researchers have also called for more transparency in how AI applications are trained (İpek et al., 2023), along with more interdisciplinary collaboration between educators and technologists to ensure AI systems meet complex educational needs effectively (Chiu et al., 2023; Zawacki-Richter et al., 2019).

2.4 Fidelity as an evaluative framework for situated learning environments

The increasing adoption of learning environments in education is promising; however, for learning to be effective, it is essential to establish whether the environment captures the fundamental features of the real task and environment while eliciting realistic behaviors (Harris et al., 2020). Fidelity, defined as the accuracy between "the real-life" contextual circumstances and the digitally created immersive environment, is central to this evaluation (Bjørn et al., 2024).

2.4.1 Types of fidelity for situated learning

Numerous conceptualizations of fidelity exist, including environmental fidelity (Rehmann, 1995), equipment or technical fidelity (Hontvedt and Øvergård, 2020), social fidelity (Bjørn et al., 2024; Sinatra et al., 2021), psychological fidelity (Schiflett et al., 2004; Harris et al., 2020), functional fidelity (Alexander et al., 2005), physical fidelity (Birbara and Pather, 2021; Harris et al., 2020), among many others. While it is often assumed that higher fidelity automatically enhances learning outcomes, this claim lacks empirical support (Schiflett et al., 2004; Sinatra et al., 2021). Moreover, achieving high levels of fidelity in many of these dimensions can be resource-intensive, requiring substantial time and resources. Therefore, it is important to carefully determine which aspects of the real-world environment should be implemented and to design scenarios, artifacts, and activities that directly support learning objectives (Bjørn et al., 2024). Since situated learning environments aim to replicate authentic contexts, facilitate expert interactions, and provide scaffolded practice and reflection, this study focuses on three key fidelity types: functional physical fidelity, psychological fidelity, and social fidelity.

2.4.2 Physical fidelity

Physical fidelity refers to the degree of realism provided by the visual and physical elements of a virtual environment, including its visual representation, behavior, and adherence to the laws of physics (Harris et al., 2020). In situated learning environments, physical fidelity is often associated with the visual resemblance of objects and spaces to their real-world counterparts. For example, in a poster session setting, physical fidelity ensures that elements such as poster boards, research posters, and seating arrangements mirror their real-world equivalents. While research suggests that low- and even zero-physical fidelity environments can serve as efficient training tools (Toups Dugas et al., 2011), high physical fidelity can still enhance immersion and engagement (Slater et al., 2022) and thus should not be isolated from aspects of learning (Lowell and Tagare, 2023). To assess physical fidelity, researchers typically use direct participant reports, presence questionnaires, and behavioral observations to determine whether users perceive the environment as visually realistic and immersive (Harris et al., 2020).

2.4.3 Functional fidelity

Functional fidelity refers to the extent to which artifacts (or virtual objects) and interactions replicate the real-world functionality of their counterparts, particularly in how actions within the environment align with real-world affordances (Bjørn et al., 2024). Unlike physical fidelity, which is concerned with whether artifacts look like the real world, functional fidelity is concerned with whether artifacts serve their functions like the real world (Alexander et al., 2005). For example, in a poster session environment, a research poster should serve as an actual multimodal component, allowing users to read and use the information during interactions in meaningful ways. Functional fidelity is typically measured by observing the object's functional behaviors during task execution (e.g., whether learners interact with posters as they would in real life) and by collecting user feedback through surveys, interviews, or questionnaires to evaluate whether the simulation supports realistic interactions and effective learning (Alexander et al., 2005).

2.4.4 Psychological fidelity

Psychological fidelity refers to the degree to which a training environment replicates the psychological demands, decision-making, and cognitive processes of real-world tasks (Gray, 2019). This includes the extent to which learners must analyze information, adapt their responses in real-time, manage cognitive load, and engage in authentic social interactions, ensuring that the task elicits the same mental effort, problem-solving, and communicative complexity required in real-world scenarios. Psychological fidelity is often considered the most relevant attribute for the transfer of learning (Harris et al., 2020). To achieve psychological fidelity, learning environments must identify the cognitive and performance requirements of real-world tasks and design scenarios that elicit these processes effectively. Measurements are then used to evaluate whether the simulation successfully engages users in these processes. Cognitive load is also a particularly relevant measure in education and training, as maintaining an optimal level of load is critical for successful learning outcomes (Kirschner, 2002).

2.4.5 Social fidelity

Social fidelity, also referred to as interactional fidelity in socio-technical systems (Hontvedt and Øvergård, 2020), is defined as the

extent to which the social aspects of a virtual character emulate real-world social interactions (Sinatra et al., 2021). This includes the realism of content and interaction patterns, enabling learners and agents to collaborate, coordinate, and create shared meaning effectively. Pedagogical agents are simulated characters that interact socially with users to support learning, and can serve as teachers, coaches, peers, or emotional supporters, and can influence learning in profound ways (Sinatra et al., 2021). Social fidelity is typically assessed using a combination of behavioral observations and self-reported measures. Behavioral assessments focus on user engagement with virtual agents and metrics such as time-on-task, while self-reported measures involve questionnaires or interviews to capture users' perceptions of social presence, connectedness, and the naturalness of their interactions with the agents (Sinatra et al., 2021).

As fidelity is crucial for any learning environment, there is thus a need to evaluate how realistic it is before moving forward. This evaluation process is integral to the operationalization of the VR-AI environment, where the theoretical fidelity is translated into tangible design and learning tasks to ensure the environment functions as intended.

3 VR-AI environment operationalization

This section first explains how the learning environment was designed based on educational theories, explicit learning outcomes, and technological affordances. It then details the fine-tuning of AI agents and the development of learning tasks.

3.1 VR-AI environment development

3.1.1 Developing the virtual environment

The VR environment was developed using *Unity3D* software and deployed on a Meta Quest 3 headset. The visual set up of a conference hall and poster boards was determined by the primary researcher's own experience and confirmed by domain experts. Assets from the Unity Asset Store were used as objects of the poster session environment. To ensure readability, the posters are billboard-sized instead of the typical $64'$ x $48'$ dimensions. The posters were from real researchers; one was adapted with informed consent and permission, and the other was created based on Fuhrman et al. (2021) research article. Both posters served as functional artifacts containing the four major research sections, graphs, and relevant visuals. The AI agents' visual representations were created using *Ready Player Me*, a 3D Avatar Creator.

3.1.2 Developing the learning tasks

Narratively in the environment, learners attend three conference days (three learning sessions) with scaffolded tasks. On the first day of the conference, the Major Professor agent guides the learner around the conference hall and invites the learner to observe how experts interact with the Poster Presenters. On the second day of the conference, the Major Professor encourages the learner to interact with the Poster Presenters independently. On the third and final day of the conference, the learner is tasked with presenting their own research. On each of these days, the Major Professor explicitly instructs learners to pay attention to the socio-rhetorical conventions of the tasks.

In this paper, we report on the development and piloting of only Day 2. Day 2 was chosen to demonstrate proof-of-concept because of its pedagogical and technical complexity: both the Poster Presenter and Major Professor agents needed to demonstrate spontaneous yet believable socio-rhetorical behavior and dialogue. There were two tasks for Day 2: interacting with the Poster Presenters and completing a guided reflection with the Major Professor. The tasks are further detailed below:

Upon entering the environment, the learner was greeted by the Major Professor, who welcomed them to the conference and the poster session. He explained that poster sessions are a great opportunity to learn about research and connect with other scholars. The Major Professor encouraged them to read the posters and ask the Poster Presenters questions. He suggested a list of key questions:

1. Why is this an important topic to study?
2. What problem is this research addressing?
3. How did you study this?
4. What are your main findings?
5. What is the biggest takeaway from this study?
6. What are the practical applications of these findings?

Following this, learners interacted with two Poster Presenters about their research (see Figure 1). Each Poster Presenter gave a brief overview of their study and invited comments and questions. The participants engaged in conversation with both presenters.

Upon task completion, learners returned to the Major Professor. The Major Professor led a reflection session using guided questions such as, "How did the presenter make a case for the importance of their study?" or "What would have been a better way of showing the impact of the study?" At the end of the session, the Major Professor congratulated the participant on a job well done and wished them luck in preparing for Day 3 of the poster session.

3.1.3 Customizing the AI agents

The AI agents were instantiated using *InWorld*, an AI game-engine platform that creates virtual characters with customized personalities and domain-specific knowledge. Since *InWorld* integrates GPTs, it allows for the adaptation of discourse community knowledge to develop agents that behave as credible members of their academic discipline. The technology enables dynamic, real-time conversations, facilitating natural back-and-forth dialogue between participants and the agents. Each agent was fine-tuned and configured to present information in ways consistent with disciplinary values and practices. Their responses were informed by a dataset of authentic dialogue samples collected from domain experts in a previous pilot study (Tan et al., 2023b). The output was further refined using common prompts aligned with the task's goals and intended learning outcomes.

Each Poster Presenter agent was first assigned a physical appearance and a name. Then, each presenter was given unique background information and a distinct personality to differentiate them from one another. For example, one of the presenters is named Yvette Fahey. She is a second year PhD student in the department of Industrial Engineering at a large mid-western university in the
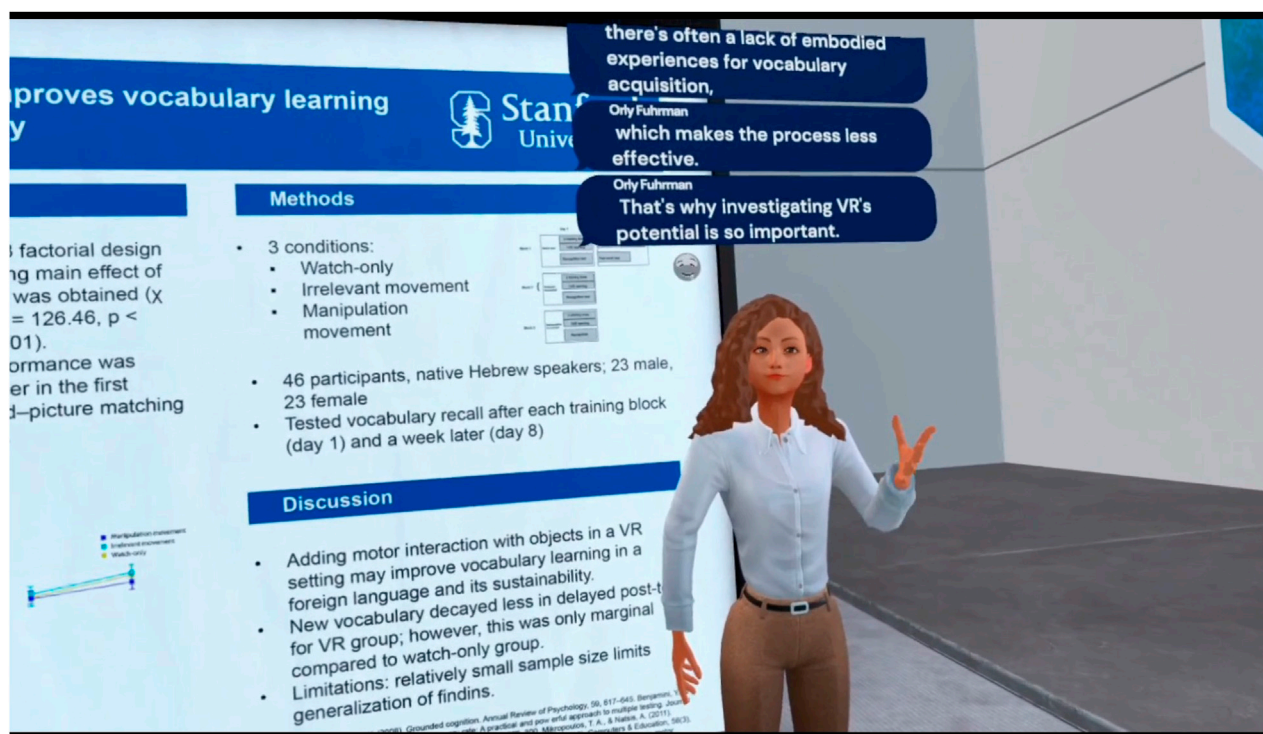
FIGURE 1
Interacting with a Poster Presenter from a participant's POV.

United States, who loves to play Overcooked 2 in her free time, and has seven cats. She has a friendly demeanor and tends to give comprehensive but engaging responses. Each agent was also given some context of their environment, role, and relationship to the other agents using natural language description. For example:

> {Character} is currently a Poster Presenter at Prestigious Conference 2024.

> {Character} is standing in front of her poster board and is excited to share her research with scholars worldwide. {Character} references her poster often when presenting her research.

> {Character}'s major advisor is John Smith, the keynote speaker for this conference.

Next, they were each given domain-specific knowledge about their own research study. For example, Yvette has the following description for her introduction section:

> {Character}'s introduction section: This study describes the process of developing a teamwork measurement system by investigating cooperative video game environments for teamwork assessment. The work aims to provide teamwork measurement and testbed design guidance through cooperative games. Cooperative video games have been shown to foster prosocial behaviors, communication, and cooperative activities. However, work is needed to establish the relationship between

cooperative features and teamwork behaviors and investigate the internal validity of these environments as assessment testbeds.

Finally, the last step was to imbue the Poster Presenters with the unique socio-rhetorical goals of the disciplinary community. The poster session move/step framework (communicative goals and strategies), adapted from a prior pilot study (Tan et al., 2023b) and previous research (adapted from Swales and Feak, 2012; Yoon and Casal, 2020), was used to ensure that each move and step included specific training phrases. Dialogue examples for Moves 1, 7, and 8 are detailed in Table 1.

The Major Professor agent, Professor Long, went through a similar instantiation process where he was given a physical appearance, name, personality, and socio-rhetorical knowledge of the community. Unlike the Poster Presenters, the Major Professor was programmed to take the learner through a guided debriefing at the end of the poster session. The debriefing aimed to raise awareness of the disciplinary community's socio-rhetorical knowledge. The Major Professor did so by asking reflective questions based on the learner's experience after the learning task. To ensure that each move was addressed, the poster session move/step framework was used (see Table 2).

3.1.4 Summarizing the VR-AI learning environment

Requirements were developed to translate learning theories, objectives, and theoretical affordances into design features. Elements for situated learning environments were drawn from Herrington and Oliver (2000). Socio-rhetorical knowledge

TABLE 1 Examples of Poster Presenter dialogue based on socio-rhetorical goals.

Socio-rhetorical value	Rhetorical strategy	Example dialogue
Demonstrating Research Need	Claiming centrality	"Hi, are you interested learning about how I used video games to study teamwork?"
	Providing general background	"When I was researching teamwork behaviors, I found that … "
	Reviewing previous research	"The Salas 2014 paper was really influential to my motivation in understanding how teamwork competencies are assessed."

TABLE 2 Major Professor agent's training phrases for the socio-rhetorical moves.

Socio-rhetorical value	Moves	Example dialogue
Demonstrating Research Need	Move 1: Establishing a territory	• Do you remember how the presenter introduced their research topic? • How did the presenters make a case for why this research area is an important one?
	Move 2: Identifying a niche	• Do you remember how the researcher introduced the problem? • Was the need for the research compelling? If yes, how so? If not, how would you have made it more compelling?
	Move 3: Introducing the study	• How did the presenters introduce the main purpose of the research? • Does the research purpose address the research need that they identified? How did they do that?
Demonstrating Research Integrity	Move 4: Summarizing research design and methods	• In your opinion, did it give you a good sense of how the study was carried out? Why do you think so? • Were there any similarities in the key pieces of information that the presenters included in their snapshot of the methodology? Were there any differences?
Demonstrating Research Contribution	Move 5: Presenting main findings	• What information did both researchers include when presenting the main findings of their study? • Did the researcher offer an interpretation of the findings? What made it effective/ineffective?
Demonstrating Research Contribution	Move 6: Stating value of research	• Did the presenter make a compelling case for the value of the research? If so, what made it compelling for you? • Could you see the research's contribution to your own work?
Exchanging Research and Ideas	Move 7: Dialoging with fellow researchers	• How did this research inspire your own work? • Were there any intersections at all that you found interesting? What was it?
Community Building	Move 8: Building community	• Were you able to gain any leads on new connections through your conversation? • Did you exchange contact information to stay in touch?

elements were gathered from a prior study (Tan et al., 2023b), which identified three social goals (initiating newcomers, facilitating research exchange, and building community) and three rhetorical goals (demonstrating research need, research integrity, and research contribution). Additionally, authentic user behavior, dialogue, language use, and expectations from the same study informed the design features of the learning environment.

Table 3 synthesizes this alignment, mapping Herrington and Oliver (2000) situated learning elements to socio-rhetorical learning goals, design features, and technological implementations. For instance, the *authentic context* requirement was operationalized through a virtual conference hall populated with AI agents representing diverse researchers, while *authentic activities* were embedded in learning tasks where learners negotiated feedback with AI agents. The AI-driven agents, trained on discipline-specific corpora, were designed to emulate expert behaviors, such as questioning research integrity or modeling rhetorical strategies like demonstrating research contribution. VR affordances, such as spatial immersion, enabled learners to engage in activities mirroring real-world academic practices (e.g., presenting posters, critiquing research). This aligned approach ensured that each design choice directly supported the acquisition of socio-rhetorical knowledge, the ultimate learning objective.

4 Methods

4.1 Research objectives

The environment was evaluated for its physical, functional, psychological, and social fidelity to ensure it met pedagogical requirements.

4.2 Participants

Ten faculty members and 10 graduate students participated in a test session. Faculty members had to be either an associate, assistant,

or full professor and must have attended more than 10 academic conferences. Students had to be currently enrolled as graduate students and have attended at least one poster session at a conference (see Table 4). All participants had normal or corrected-to-normal vision.

4.3 Measures

Table 5 lists the dependent variables, measurement metrics, and data collection frequency for evaluating fidelity in the VR-AI learning environment.

Physical fidelity was evaluated using the Igroup Presence Questionnaire (IPQ) (Igroup, 2000) to assess realism and the extent to which participants felt like they were "at a real conference" engaging with "real people." The IPQ consists of 14 questions measuring four factors: General Presence, Spatial Presence, Involvement, and Experienced Realism (Table 6).

Additionally, interview data was gathered to elicit qualitative insights into participants' perceptions of realism. To convert the raw IPQ scores into something more interpretable, Melo et al. (2023) qualitative grading description tool was used to provide a more meaningful interpretation of the environment (see Table 7).

Functional fidelity was evaluated using observational data and interviews. Users' interactions with artifacts (research posters) were observed to see whether they reflected real-world conference behavior, such as reading, questioning, and discussing content. Interviews further explored participants' perceptions of the usability and functionality of these artifacts.

Psychological fidelity was evaluated using the NASA-TLX (Hart and Staveland, 1988) to measure the perceived demands of the task and a 7-point Likert-scale questionnaire assessing how well the socio-rhetorical values of the discourse community were embodied in the agents and learning tasks (see Table 8). Follow-up interviews were conducted to determine whether the task reflected the psychological aspects of research discussions of critically processing, synthesizing, and articulating research thoughts.

Interactional fidelity was evaluated using relevant sub-scales of the IPQ (Igroup, 2000), observational data, and a semi-structured interview. The analysis included participant engagement with AI agents, while interviews captured perceptions of social presence, conversational flow, and authenticity in interactions.

4.4 Procedure

Participants were welcomed into a private room fitted with a Meta Quest 2 headset, and their Interpupillary Distance (IPD) was adjusted to ensure visual comfort and optimal clarity. They were given a brief tutorial on how to use the controllers and headset. All movement within the VR environment was controlled with the joysticks on the controller and did not require physical movement. Participants stood in place while they navigated virtually in the VR. Once comfortable, participants were instructed to stand within a 4′x4′ marked area, ensuring a safe, obstruction-free space.

Participants were then virtually transported into the poster session environment, where they completed Day 2 of the poster session scenario. During the 30-min learning task, participants engaged in observing, questioning, and discussing research posters with AI agents. Participant interactions were screen-recorded and observed throughout the session to assess how they engaged with research posters and AI agents.

Immediately after completing the task, participants completed three questionnaires to assess different aspects of the virtual learning environment: (1) the Igroup Presence Questionnaire (IPQ) to measure physical and social fidelity, (2) the NASA Task Load Index (NASA-TLX) to assess cognitive workload, and (3) a 7-point Likert-scale questionnaire to evaluate how well the socio-rhetorical values of the discourse community were embodied in the AI agents and learning tasks. Following the questionnaires, a 25-min semi-structured interview assessed participants' psychological and social fidelity perceptions. The interview focused on three dimensions: the Poster Presenters, the Major Professor, and the Learning Tasks, exploring whether these elements aligned with the discourse community's socio-rhetorical expectations. Participants were also asked about usability issues (e.g., frustrations, pain points, areas for improvement).

4.5 Data analysis

The IPQ, NASA-TLX, and socio-rhetorical value ratings were analyzed using descriptive statistics. For the semi-structured interview data, thematic analysis (Byrne, 2022) was employed. A deductive approach was adopted as this process was guided by the research objectives and the design of the interview questions. Specifically, *a priori* codes were created for each of the six socio-rhetorical goals, in addition to codes for usability and improvement suggestions. New codes were also generated based on reoccurring participant responses.

5 Results

5.1 Physical fidelity

5.1.1 IPQ

All participants rated the environment highly in *spatial presence* ($M = 5.5, SD = 1.2$), *general presence* ($M = 5.6, SD = 0.7$), and *involvement* ($M = 4.7, SD = 1.5$). However, *experienced realism* received a lower rating ($M = 3.8, SD = 1.6$) (see Figure 2). Using Melo et al. (2023) qualitative grading description tool, all of the subscales received an "A" grade except for *experienced realism*, which received a "B."

5.1.2 Observational and interview data

Observations indicated that all participants were immersed in the environment and appeared to respect the general physics of the world, such as avoiding physical objects and walking around people. Interview responses supported these findings, with all participants describing the virtual environment as immersive and engaging.

> "Environment-wise, it was kind of dead on. The conference hall, and the poster presentations. And there are people milling about, and there's like a person that comes up to the presenter."

> "The characters, they all looked very real. And the environment too, it's like what you can see in a conference."

TABLE 3 Operationalization and development.

Situated learning elements	Implementation of socio-rhetorical knowledge	Poster session design features	Technological affordance
Provide authentic context that reflects the way the knowledge is used in real life	• Socio-rhetorical tasks must occur in environment reflecting real context • Socio-rhetorical actors must mirror real context • Socio-rhetorical artifacts must mirror real context • Socio-rhetorical purpose, language, communication modes, and behaviors must mirror real context	• A physical conference hall environment with multiple poster boards and presenters • A community of AI researcher and poster presenter agents of varying levels, disciplines, and background • Visual posters and presenters depict and discuss real research • AI poster presenter agents are there to showcase research, receive feedback, and build relationships with other researchers • AI conference-goer agents are there to learn about new research, mentor, and strengthen relationships with other researchers	• VR can virtually recreate conference halls, poster boards, and community of virtual agents • AI agents can be trained on behaviors (e.g., dialoguing, challenging, encouraging) • AI agents can be trained on discipline-specific corpora and identities
Provide authentic activities	• Socio-rhetorical activities that mirror those in real context • Tasks must be of equal socio-rhetorical content and complexity	Poster session activities learners will participate in include • Reading posters and watching others present • Talking to other poster presenters about their research • Presenting own research poster to other researchers	• VR can enable movement, navigation and interaction mechanisms for immersive participation in activities • AI agents can be trained on research areas and socio-rhetorical conventions
Provide access to expert performances and modelling of processes	• Opportunities to observe how experts perform at an authentic task • Opportunities to understand experts' cognitive process	Learners get to watch • Expert poster presenters present their research • Expert researchers dialogue with each other	• VR allows learners to immersive observe examples of expert performance in context • AI agents can be trained to produce a model output for observation of the learners
Provide multiple roles and perspectives	• Tasks that require taking on different socio-rhetorical roles • Opportunities to observe socio-rhetorical perspectives from various backgrounds	• Activities for learners to take on roles of observing, dialoguing and presenting research • Opportunities for learners to learn from researchers of varying levels, disciplines and backgrounds	• AI agents can be trained to have different roles of poster presenter, audience member, major professor • AI agents can be trained to have different disciplines, different levels of interests, and different perspectives to produce robust conversation
Support collaborative construction of knowledge	• Interactional tasks that allow learners and agents to learn and negotiate socio-rhetorical knowledge with each other	• Activity where learners talk to agents about agent's research to share and negotiate knowledge • Activity where agents talk to learner about learner's research to share and negotiate knowledge	• VR can enable face-to-face, interactional conversations between learners and agents • AI agents can be trained to ask questions, challenge, and collaborate
Promote reflection to enable abstractions to be formed	• Opportunities to reflect on socio-rhetorical context and purpose • Opportunities to compare expert vs non-expert socio-rhetorical performances	Activity where learner is asked to reflect on • Socio-rhetorical conventions and expectations of poster presentations • Difference between effective and ineffective poster presentations	• VR provides opportunities for learners reflect on activities as they experience it • AI agents can be trained to ask reflective questions that adapt to the learner
Promote articulation to enable tacit knowledge to be made explicit	• Opportunities for students to articulate their socio-rhetorical learning • Tasks that necessitate explicitly talking about socio-rhetorical knowledge	Guided reflection activity where learner is asked to articulate • Effective and ineffective socio-rhetorical strategies • How they would apply socio-rhetorical strategies to their own research	• VR can enable face-to-face, pedagogic conversations between learner and agents • AI agents can be trained to encourage learners to articulate and apply their new learning
Provide coaching and scaffolding by the teacher at critical times	• Explicit teaching of socio-rhetorical concepts by an expert • Scaffolded opportunities to observe and practice socio-rhetorical concepts	• Scaffolded tasks that take learner from observing > dialoguing > presenting • A major professor agent that serves as mentor and will provide explicit guidance on key socio-rhetorical practices to observe • Major professor agent adapts pedagogic feedback to learner responses during guided reflections as assessments	• VR can provide environments to carry out scaffolded activities authentic virtual contexts, with control over pedagogic elements (number of people, questions, etc.) • AI agents can be trained to provide instruction and adaptive guidance to learners

TABLE 3 (*Continued*) Operationalization and development.

Situated learning elements	Implementation of socio-rhetorical knowledge	Poster session design features	Technological affordance
Provide integrated assessment of learning within the tasks	• Opportunities for students to practice and showcase socio-rhetorical learning • Multiple indicators of socio-rhetorical learning	• After observation task, learners are assessed and provided feedback on socio-rhetorical expectations • After dialoguing task, learners are assessed and provided feedback on socio-rhetorical strategies • After presenting task, learners are assessed and provided feedback on integrating socio-rhetorical expectations to other research areas	• VR can provide in-environments opportunities to observe learners performance • AI agents can be trained to assess learner's performance and provide feedback based on performance

TABLE 4 Participant demographics.

Group	Gender	Age	Discipline	Title/Year in school
Faculty members	Male (n = 7) Female (n = 3)	35–44 (n = 5) 55–64 (n = 4) 65+ (n = 1)	Applied Linguistics (n = 3) Communications (n = 1) Architecture (n = 2) Design (n = 2) Engineering (n = 2)	Full professor (n = 3) Associate professor (n = 3) Assistant professor (n = 4)
Graduate Students	Male (n = 4) Female (n = 6)	25–34 (n = 6) 35–44 (n = 4)	Applied Linguistics (n = 6) Engineering (n = 4)	>4 years (n = 1) 3 years (n = 6) 2 years (n = 3)

TABLE 5 Dependent variables and measurement metrics for fidelity evaluation.

Dependent variable	Metric	Units	Frequency
Physical Fidelity	IGroup Presence Questionnaire (IPQ)	14-item Likert scale (1–7)	Post-experiment
	Semi-structured interviews	Qualitative responses	Post-experiment
Functional Fidelity	Observations of interactions with research posters	Behavioral assessment	During task
	Semi-structured interviews on research poster functionality	Qualitative responses	Post-experiment
Psychological Fidelity	NASA Task Load Index (NASA-TLX)	6 workload dimensions (1–20)	Post-experiment
	Socio-Rhetorical Questionnaire	Likert scale (1–7)	Post-experiment
	Semi-structured interviews on task	Qualitative responses	Post-experiment
Social Fidelity	IGroup Presence Questionnaire (IPQ)	14-item Likert scale (1–7)	Post-experiment
	Observations of participant-agent interactions	Behavioral assessment	During task
	Semi-structured interviews on participant-agent interactions	Qualitative responses	Post-experiment

> "It's super close to what a poster session is. Big room, people walking around, I liked that. And that you can walk around and visit any person was cool."

5.2 Functional fidelity

5.2.1 Observational data

Observations revealed that half of the participants (n = 10) read the research poster before engaging with the Poster Presenter, while the other half either became too engaged in the interaction or simply overlooked this step. Those who did engage with the poster skimmed each major section (Introduction, Results, Discussion, Methods) and used the content to guide their discussion with the presenter. Some even challenged the presenter's methods (n = 7) and asked about the literature review (n = 5).

5.2.2 Interview data

Interview responses supported the observational data. While participants generally found the posters functional, some noted that the oversized poster boards made it difficult to glance back and forth while conversing, requiring them to walk back and forth, a deviation from real-life interactions.

TABLE 6 Items of the IPQ and its subscales.

Factor	Item
General Presence	In the computer-generated world, I had a sense of "being there."
Spatial Presence	Somehow I felt that the virtual world surrounded me
	I felt like I was just perceiving pictures
	I did not feel present in the virtual space
	I had a sense of acting in the virtual space, rather than operating something from outside
	I felt present in the virtual space
Involvement	How aware were you of the real world surrounding while navigating in the virtual world? (i.e., sounds, room temperature, other people, etc.)?
	I was not aware of my real environment
	I still paid attention to the real environment
	I was completely captivated by the virtual world
Experienced Realism	How real did the virtual world seem to you?
	How much did your experience in the virtual environment seem consistent with your real-world experience?
	How real did the virtual world seem to you?
	The virtual world seemed more realistic than the real world

TABLE 7 Melo et al. (2023) qualitative grading description tool for the IPQ.

General presence	Spatial presence	Involvement	Experienced realism	Grade	Adjective	Acceptability
≥4.41	≥5.25	≥4.87	≥4.50	A	Excellent	Acceptable
≥4.07	≥4.76	≥4.50	≥3.75	B	Very Good	
≥3.86	≥4.50	≥4.00	≥3.38	C	Satisfactory	
≥3.65	≥4.25	≥3.75	≥3.00	D	Marginal	Marginally acceptable
≥3.47	≥4.01	≥3.38	≥2.63	E	Unsatisfactory	
<3.47	<4.01	<3.38	<2.63	F	Unacceptable	Not Acceptable

> "There was a challenging visual thing. I needed to be close enough for them to hear me, but I cannot see the panels."

> "I think I wanted smaller panels to fit within the field of vision, but at the same time I liked how readable it was."

> "If I was further away then the labels became hard to read, but if I moved closer then I could not see the presenter, so I felt like."

5.3 Psychological fidelity

5.3.1 NASA-TLX

Participants reported the following scores for each NASA TLX subscale: mental demand ($M = 13.7$, $SD = 3.9$), physical demand ($M = 6.4$, $SD = 5.2$), temporal demand ($M = 9.5$, $SD = 6.2$), performance ($M = 11.2$, $SD = 5.0$), effort ($M = 11.2$, $SD = 5.0$) and frustration ($M = 8.4$, $SD = 5.7$) (see Figure 3).

5.3.2 Socio-rhetorical questionnaire

The overall mean for rhetorical goals was ($M = 5.20$, $SD = 1.49$), with relatively small standard deviations, indicating general agreement among participants. *Demonstrating Research Need* ($M = 5.25$, $SD = 1.25$) and *Demonstrating Research Contribution* ($M = 5.25$, $SD = 1.37$) scored the highest. *Demonstrating Research Integrity* also had high ratings ($M = 5.1$, $SD = 1.80$). These scores suggest that the rhetorical goals were well represented in the environment (see Figure 4).

The overall mean for social goals was ($M = 4.05$, $SD = 2.09$), with large standard deviations, indicating greater variability in participant responses. *Community Building* ($M = 4.25$, $SD = 1.99$) and *Development of Emerging Scholars* ($M = 4.80$, $SD = 1.99$) received moderately high scores with the exception of the Poster Presenters, who were not designed to "mentor" the learner, while *Exchange of Research and Ideas* received lower ratings ($M = 3.45$, $SD = 2.21$). These scores suggest that while social goals were present in the environment, participants had more varied perceptions of their representation.

TABLE 8 Interview questions assessing goals across three dimensions.

Socio-rhetorical goals	Agents/Tasks	Questions
Mentoring of emerging scholars	Poster Presenters agents	How well was this value present? What would you have liked to see to make it better?
	Major Professor agent	How well was this value present? What would you have liked to see to make it better?
	Learning Tasks	How well did the learning tasks bring awareness to this value? How similar was the task to its real-life counterpart? What would you have liked to see to make it better?
Exchanging research and ideas	Poster Presenters agents	How well was this value present? What would you have liked to see to make it better?
	Major Professor agent	How well was this value present? What would you have liked to see to make it better?
	Learning Tasks	How well did the learning tasks bring awareness to this value? How similar was the task to its real-life counterpart? What would you have liked to see to make it better?
Building Community	Poster Presenters agents	How well was this value present? What would you have liked to see to make it better?
	Major Professor agent	How well was this value present? What would you have liked to see to make it better?
	Learning Tasks	How well did the learning tasks bring awareness to this value? How similar was the task to its real-life counterpart? What would you have liked to see to make it better?
Demonstrating Research Need	Poster Presenters agents	How well was this value present? What would you have liked to see to make it better?
	Major Professor agent	How well was this value present? What would you have liked to see to make it better?
	Learning Tasks	How well did the learning tasks bring awareness to this value? How similar was the task to its real-life counterpart? What would you have liked to see to make it better?
Demonstrating Research Integrity	Poster Presenters agents	How well was this value present? What would you have liked to see to make it better?
	Major Professor agent	How well was this value present? What would you have liked to see to make it better?
	Learning Tasks	How well did the learning tasks bring awareness to this value? How similar was the task to its real-life counterpart? What would you have liked to see to make it better?
Demonstrating Research Contribution	Poster Presenters agents	How well was this value present? What would you have liked to see to make it better?
	Major Professor agent	How well was this value present? What would you have liked to see to make it better?
	Learning Tasks	How well did the learning tasks bring awareness to this value? How similar was the task to its real-life counterpart? What would you have liked to see to make it better?

5.3.3 Semi-structured interviews

Overall, participants reported that the learning tasks–dialoguing with the Poster Presenters and reflecting with the Major Professor–demonstrated psychological fidelity by engaging them in research communication and rhetorical reflection. The Poster Presenter task successfully engaged participants in processing, synthesizing, and articulating research ideas, requiring them to construct questions and evaluate responses in ways that mirrored real-world academic exchanges. Most (n = 8) found the cognitive demands appropriate, though some (n = 4) noted that poster presenters could have provided more depth and adaptability in their responses to follow-up questions.

The reflection task with the Major Professor demonstrated mixed psychological fidelity, reinforcing rhetorical awareness but introducing cognitive workload that reduced opportunities for active engagement. Most faculty participants (n = 7) noted that the Major Professor effectively guided learners through key research communication strategies, with many stating that his mentoring closely resembled their own teaching styles.

Some faculty participants (n = 5) even reported that he provided more substantial mentorship than they typically do, offering clear conventions and structured guidance on how to engage in academic discourse. Students (n = 7) noted that the Major Professor was a helpful mentor, gave them key conventions to look out for, and provided guidance on how to participate in these conventions. Examples of participant excerpts include:

> "I've never had a major professor give me pointers for a poster session. I've always kind of just been like, turned loose at a conference. And I would just fake it the entire time. So, this was helpful, that I come back to interact and be given encouragement."

> "It's a nice set up, telling the students what to look out for and then the debriefing. The professor gave a good structure so that even new graduate students can participate and ask good questions."

However, students found the task cognitively demanding. Many struggled to remember the six prompts provided by the Major Professor. They felt that the debriefing required them to retrieve information, making the experience feel more like a memory test than a critical reflection exercise. Participants reported feeling unprepared and pressured, noting that in a real setting, they would not be expected to recall every detail from multiple poster discussions, making the task feel artificial and disconnected from authentic academic experiences. Examples of participant excerpts include:

> "And I thought, I'm never going to be able to remember all of this. Even though I knew they were typical questions. I think I remembered maybe three or four of them. But then also being able to remember the answers from two different people . . . I knew I was not going to be able to remember."

> "Why is the professor asking me things that he did not warn me about? It felt like an exam and it was a bit stressful. And I thought, oh no, I'm going to fail this test."

> "I think the questions, they were too many questions. Yeah, maybe highlight something and then I can focus on it. Because it's kind of hard to memorize."

5.4 Social fidelity

5.4.1 IPQ (experience realism)

The sub-scale *experienced realism* of the IPQ was used as a measure of social fidelity. *Experienced realism* received a lower rating ($M = 3.8$, $SD = 1.6$) (see Figure 2). Using Melo et al. (2023) qualitative grading description tool, this subscale received a "B" grade.

5.4.2 Observational and interview data

Overall, observational data showed poor social fidelity, particularly in the AI agents' inability to manage conversational flow. The agents struggled with turn-taking in two key ways: first, they frequently misinterpreted participant pauses as conversation endings, leading to interruptions; second, they delivered overly long, one-sided responses, making it difficult for participants to interject or steer the conversation. As a result, participants hesitated to engage in dialogue, fearing they would either be cut off too soon or subjected to an extended monologue.

Participant interview responses corroborated these observations. All participants reported that conversational interactions were poor as they were constantly interrupted by the AI agents, particularly the Major Professor, and the agents' responses were too long and one-sided. Below are interview excerpts:
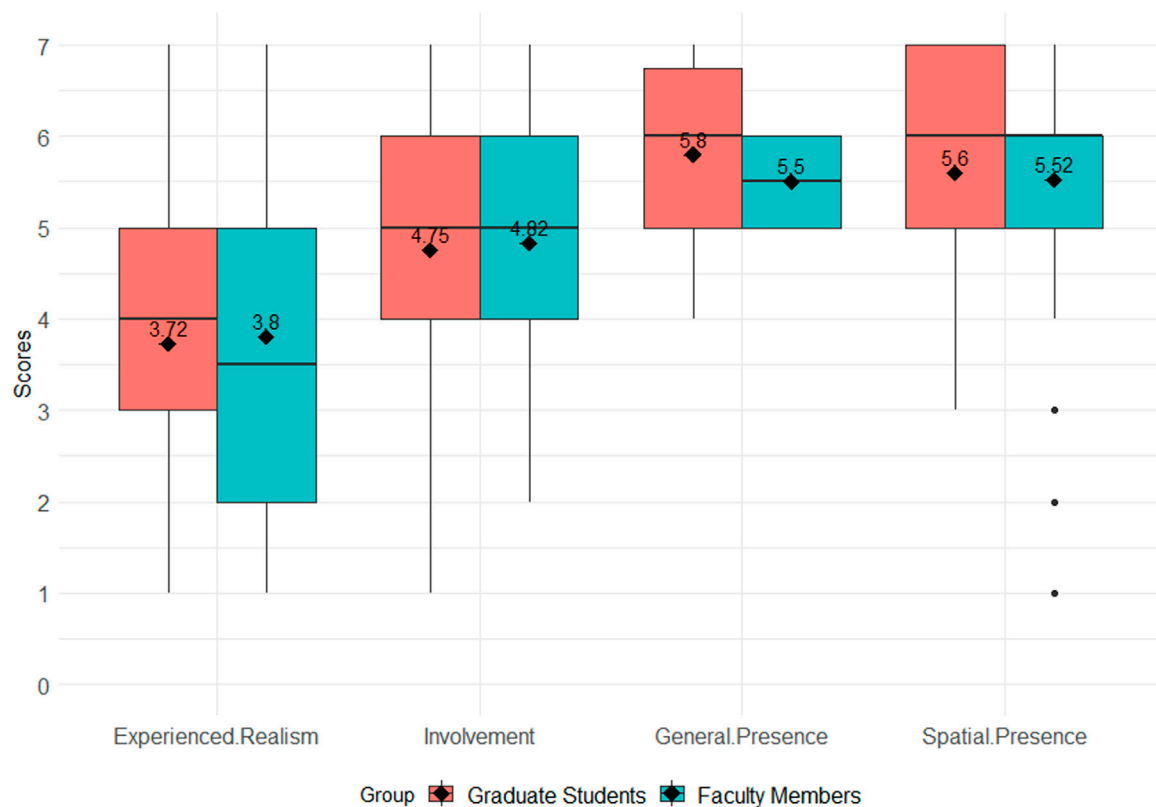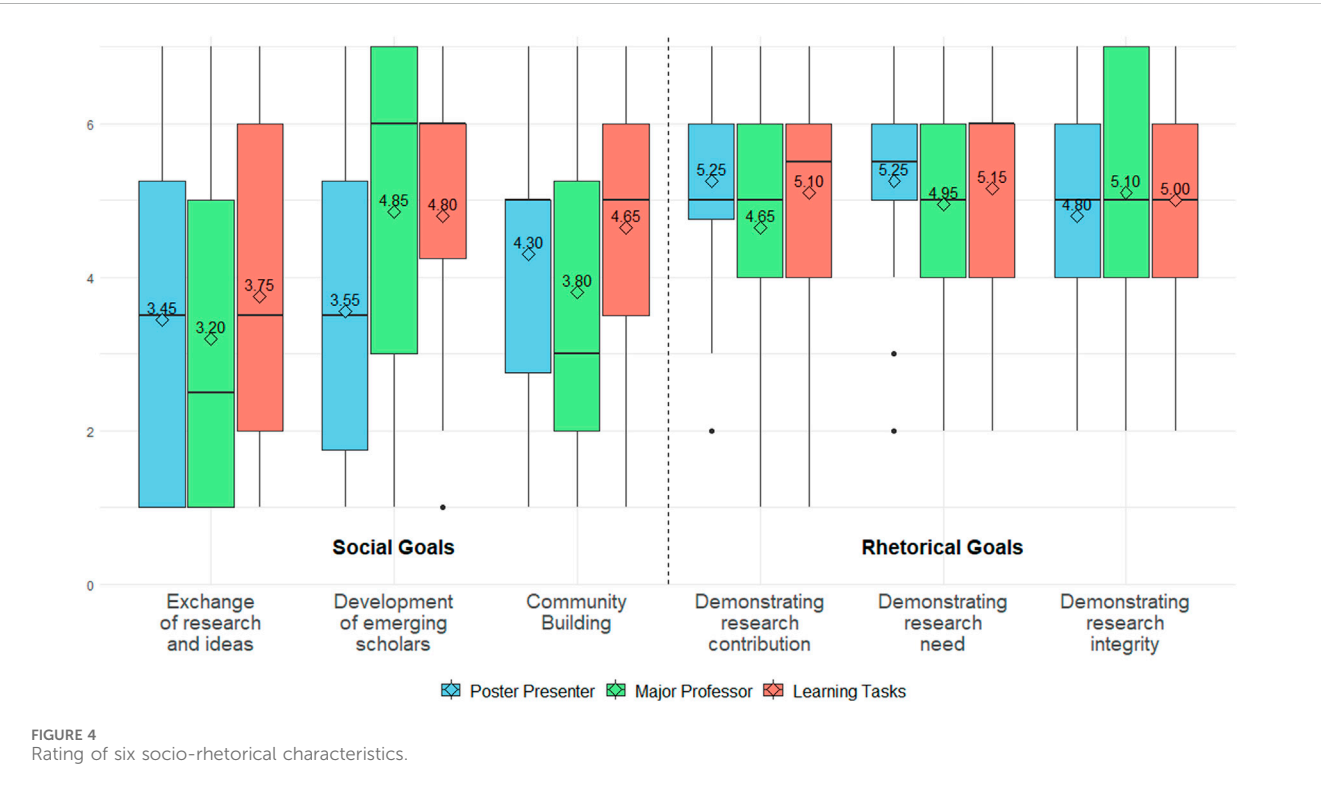

FIGURE 2
Boxplot for IPQ measures of presence across the four subscales.

FIGURE 3
NASA-TLX's measures of workload for graduate students and faculty.

FIGURE 4
Rating of six socio-rhetorical characteristics.
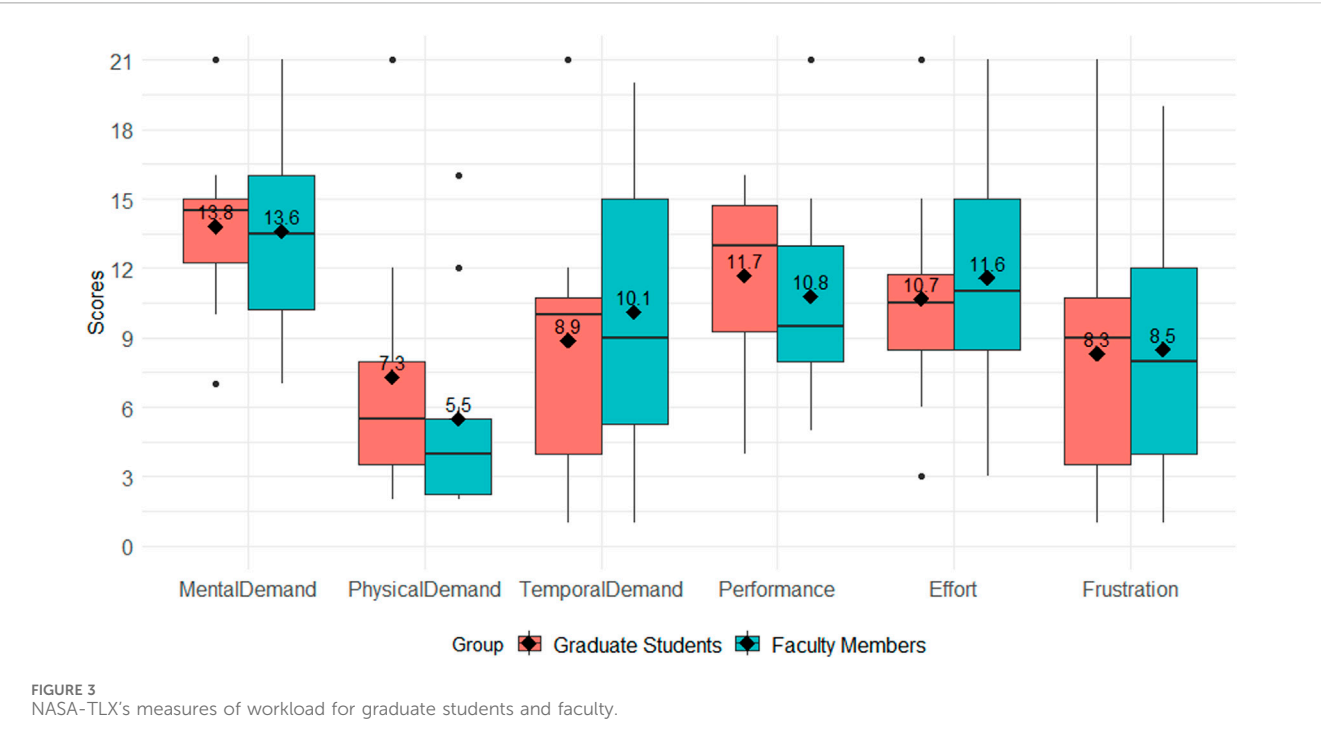
"He [Major Professor] did not wait for me to talk after the prompts and did not allow for a moment to allow a person to speak. I wished we would have had more of a dialogue. And he waited for my responses. I think that could be really valuable."

"The Major Professor especially was word vomiting but in a very, very long winded type of way. Sometimes, he even generated new responses as I was talking. Sense making was hard."

> "I wanted to be able to interrupt the presenters. I wanted shorter responses so that I could ask them more questions."

6 Discussion

This study aimed to develop, operationalize, and evaluate a VR-AI learning environment that facilitates the development of socio-rhetorical knowledge through disciplinary socialization. The environment's design was grounded in genre theory (defining what must be learned) and situated learning theory (determining how it is learned). Based on these principles, the study developed key features of the virtual environment, customized AI-driven agents, and structured learning tasks to align with authentic academic interactions and learning outcomes. The final step involved evaluating the environment's physical, functional, psychological, and social fidelity to determine its effectiveness and pedagogical viability. Ensuring that a situated learning environment successfully captures the fundamental features of real-world tasks and contexts is critical to its educational effectiveness.

Overall, physical and functional fidelity were rated highly, with participants frequently describing the simulation as feeling and operating "just like a real poster session." The realistic design of the environment, coupled with artifacts high in functional fidelity, successfully immersed learners in authentic socio-disciplinary practices. Similarly, psychological fidelity was high as the cognitive demands required to engage with the environment's tasks closely mirrored those encountered in real-world settings. Learners were required to critically engage with research presentations, analyze rhetorical strategies, and reflect on communicative effectiveness–tasks that align with the cognitive processes necessary for research socialization. While the cognitive workload for the guided reflection task was found to be too high, the results suggest that the simulation successfully supported learners in developing their awareness of socio-rhetorical conventions.

However, social fidelity was low, with participants frequently describing conversations as "not organic." Issues with turn-taking (when speakers exchange turns) and turn length (how long each speaker talks) emerged as key issues as the AI-driven agents struggled to facilitate natural dialogue. Participants noted that the lack of fluid, reciprocal exchanges limited their ability to engage meaningfully in discussions about research quality and key disciplinary concepts. Given that learning is inherently social, the interaction design must be improved to better support dynamic, back-and-forth discussions that more accurately reflect real-world academic exchanges. Enhancing these interactions will be crucial for ensuring that learners can fully engage in socio-rhetorical learning.

These interactional challenges stem from fundamental limitations in AI-driven conversation management, specifically in its simplified detection systems for turn taking. Turn-taking, a core aspect of human dialogue, is governed by complex linguistic and non-linguistic cues that signal when a speaker's turn has ended, and the next speaker should begin (Sacks et al., 1974). Human speakers naturally regulate these transitions through subtle cues such as pitch, intonation, pausing, and gaze direction. In contrast, AI-driven agents in this study relied on voice activity detection, which erroneously assumed that any pause signaled the end of a turn. This misinterpretation frequently led to interruptions, disrupting

the natural flow of conversation and reducing engagement. Additionally, the agents often delivered excessively long, one-sided responses, violating Grice's (1975) Maxim of Quantity, which states that contributions to a conversation should be as informative as necessary but not overly verbose. These extended monologues made interactions feel unnatural, diminishing the sense of reciprocal exchange and frustrating participants.

To address these limitations to increase social fidelity, several improvements are recommended. First, implementing a push-to-talk feature can provide a clear signal for turn transitions, giving participants greater control over conversational flow and reducing unintended interruptions. Second, adjusting response length is essential; agents should be programmed to provide concise, targeted responses (e.g., limiting turns to 50 words during general dialogue and up to 80 words for structured presentations or mentoring). Training agents to ask more questions and engage in active turn-taking will also encourage more dynamic and cooperative exchanges, better simulating real-world academic discussions. These refinements will be crucial in fostering more natural, interactive, and pedagogically effective conversations within the VR-AI learning environment.

6.1 Implications

This work contributes to the growing body of research on using immersive simulations with social interactions for education and training. While immersive simulations have long been used for technical training in fields such as aviation (Caro, 1973; Guthridge and Clinton-Lisell, 2023), athletics (Gray, 2019; Miles et al., 2012), and surgery (Hashimoto et al., 2018; Sutherland et al., 2006), these studies have primarily focused on hardware and software requirements to ensure reliable training outcomes. With the rise of GenAI, attention has shifted towards simulations that also support social realism. Emerging applications have begun to arise in fields like patient care (Lowell and Tagare, 2023; Carnell et al., 2022) and education (Chheang et al., 2024; Mulvaney et al., 2024), where learners must learn how to navigate social complexity while performing in their task domain. This is especially beneficial for work that requires the development of teamwork and collaboration, socialization, or interpersonal skills.

As this is a burgeoning field, this contributes to the body of work by identifying the types of fidelity required for immersive, socially rich learning experiences that allow learners to participate not just in authentic contexts, but also in authentic interactions. Physical fidelity is essential for establishing presence, making it crucial to incorporate realistic materials and artifacts—such as authentic research posters and academic settings—to simulate real-world participation. Functional fidelity ensures that these artifacts operate meaningfully within the virtual space, allowing learners to interact with research materials in ways that mirror authentic disciplinary practices. Psychological fidelity is critical for fostering cognitive engagement, requiring tasks that replicate the mental processes involved in evaluating, analyzing, and discussing research. Finally, social fidelity underpins collaborative knowledge construction and disciplinary socialization, necessitating interaction designs that enable fluid, reciprocal exchanges that reflect real-world academic discourse. While this work was designed around a poster

session context focusing on disciplinary socialization, its underlying learning mechanisms can be applied to other educational and training contexts requiring immersive and socially interactive experiences. It offers theoretical and practical contributions to the development of situated simulations, as well as methodological guidance for evaluating how specific design features can be aligned with learning goals and intended learner outcomes.

At the same time, fidelity levels must be carefully calibrated to avoid cognitive overload, as excessively high or low fidelity can hinder learning by either overwhelming learners or limiting their ability to engage in higher-order thinking (Champney et al., 2017). Rather than maximizing fidelity across all dimensions, situated learning environments should balance realism with pedagogical considerations, ensuring an authentic yet cognitively manageable experience that facilitates meaningful engagement and skill transfer. In the context of this VR-AI learning environment, achieving the right balance is crucial to ensuring that learners can authentically engage in socio-rhetorical practices without unnecessary distractions or barriers. For instance, functional fidelity in the research posters was effective because it replicated a real academic setting, allowing learners to engage in familiar knowledge negotiation. Conversely, low social fidelity in the AI agents hindered authentic research dialogue.

6.2 Limitations and future work

While this study demonstrates the potential of VR-AI learning environments for fostering socio-rhetorical learning, several limitations highlight areas for future improvement. First, social fidelity remains a challenge, as AI-driven agents struggled with natural turn-taking, response length, and dynamic interaction, limiting the authenticity of academic discourse. Future work should focus on enhancing AI-driven conversational models to better replicate the fluid, reciprocal exchanges essential for research socialization. Second, the study's participant sample, though representative of a disciplinary community, was relatively small, which may affect the generalizability of findings. Expanding the study across diverse academic disciplines and larger student populations will provide a more comprehensive understanding of how different learners engage with VR-AI environments. Additionally, this study primarily relied on a self-reported questionnaire to assess the psychological fidelity of the primary learning construct, socio-rhetorical knowledge. However, psychological fidelity is critical, as it has been established as the most important factor for real-world transfer (Gray, 2019; Harris et al., 2020). Given the complexity of this construct, self-reports alone may be insufficient, and a more robust way of evaluating psychological fidelity is needed. For example, many studies utilized a combination of self-reports and such as eye-tracking to evaluate gaze behavior (Frederiksen et al., 2020; Vine et al., 2014), pscyphophysiological measurements to evaluate stress (Slater et al., 2006) and cardiovascular activity (Ćosić et al., 2010), and EEGs to measure neural activity (Brouwer et al., 2010; Tromp et al., 2018). Finally, while this study described the development and evaluation of a VR-AI learning environment, it did not assess learning outcomes or skill transfer. Future research should include longitudinal studies to examine how engagement in VR-AI environments translates into actual intended learning outcomes over time.

7 Conclusion

This study explored how a VR-AI learning environment can facilitate socio-rhetorical learning by immersing graduate students in simulated academic interactions. By integrating trained GPT agents and structured learning tasks within a multi-fidelity framework, the simulation successfully replicated key aspects of disciplinary socialization. Findings showed that while physical, functional, and psychological fidelity were well-embodied, social fidelity remained a challenge, highlighting the complexities of designing AI-driven conversational interactions. Despite this, the VR-AI environment provided an authentic and immersive space for learners to engage with their discourse communities and navigate academic discourse in a way that traditional classroom settings often fail to achieve.

This work makes several key contributions. First, it demonstrates how situated learning theory can be operationalized in VR-AI environments to bridge the gap between classroom instruction and real-world academic participation. Second, existing research evaluating pedagogically-grounded learning environments remains limited, this work provides a structured approach to examining how different fidelity dimensions influence learning experiences. Finally, as research in academic research communication continues to evolve in the digital age, this study contributes to the broader discourse on addressing the challenges of academic socialization, while also providing a framework for the design and evaluation of VR-AI learning environments that can be adapted to other educational contexts.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Iowa State University Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AT: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review and editing. MD: Conceptualization,

Methodology, Writing – review and editing. EC: Conceptualization, Methodology, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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