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Extended Abstract—Design of Learning Content with Telepresence Robots and Virtual Agents Considering Social Presence and Embodied Interaction

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Abstract. We propose design principles grounded in the theoretical frameworks of social presence and embodied interaction, to define the roles of telepresence robots and virtual agents as learning companions in educational content. Following a research-based design approach, we integrated these theories into design principles and developed a prototype of distance learning content that incorporates telepresence robots and virtual agents. The prototype was designed to enhance learner engagement and interaction in both physical and virtual learning environments. We demonstrate how the proposed design principles inform the design of learning tasks and the roles of learning companions. Additionally, we discuss the effectiveness of these learning companions in supporting learner interaction and reducing feelings of isolation, while considering the different affordances of telepresence robots and virtual agents. Finally, we propose areas for further research and potential improvements in the design and application of such learning technologies.

Keywords: Telepresence Robot, Virtual Agent, Learning Companion, Social Presence, Embodied Interaction, Design Principle.

1 Introduction

Distance learning has expanded across various fields, as physical proximity between instructors and learners is no longer required. Following the COVID-19 pandemic, educational institutions made significant efforts to adapt classrooms and students to distance learning environments while maintaining the quality of education. Educators experimented with various strategies for conducting lectures, tutorials, group projects, lab sessions, and assessments in a remote setting [1]. These initiatives contributed to enhancing the effectiveness of remote education and promoting its application in diverse educational sectors.

However, despite these efforts, some significant barriers to distance learning persist, such as the sense of isolation experienced by students [2, 3]. In distance learning environments, many students lose motivation due to a lack of interaction and socio-cognitive engagement with instructors and peers [1, 2]. This sense of isolation is one of the primary causes of dropout in distance learning [4]. Therefore, recent developments in distance learning now focus on enhancing interaction, preventing student isolation by using learning communities or groups, and integrating synchronous and asynchronous communication and collaboration tools [3].

In this context, virtual reality (VR) emerges as a promising immersive and interactive technology for enhancing distance learning [5]. Due to its ability to create interactive, three-dimensional dynamic scenes and behavior simulations [6], the virtual agent in VR enables communication between instructors and students in a way that simulates face-to-face interaction, increasing the potential for real-time feedback [7]. Nevertheless, collaborative learning with the virtual agent in VR does not inherently guarantee productive interactions among learners. For successful VR-based learning with virtual agents [8].

The limitations of learning with virtual agents can be addressed through the use of telepresence robots. These systems facilitate bidirectional video and audio communication while navigating remote environments [9]. Telepresence robots, being physically embodied, can coexist in the same environment as users, allowing for embodied interaction. Learning through telepresence robots involves communication mediated by the robot, and when physically present, learners tend to show greater attention and intimacy toward remote peers [10], fostering more positive interactions [11]. Learning through telepresence robots involves communication mediated by the robot, enhancing attention and engagement [10], fostering positive interactions [11]. However, effective implementation requires considerations such as natural eye and body movements, gestures, and voice quality [12].

To ensure effective distance learning, designing interactive and socially engaging environments using virtual agents and telepresence robots is essential. This study follows a research-based design (RBD) approach to develop learning companion models that enhance learner interaction and reduce isolation. Through iterative development and empirical validation, we explore how virtual agents and telepresence robots can collaborate with learners in both virtual and physical environments.

1.1 Research Questions

- RQ1. What are the design principles, grounded in theoretical knowledge, for defining the roles of learning companions (telepresence robots, virtual agents) in learning content?
- RQ2. How can a prototype for learning content be developed based on research-based design principles for defining the roles of learning companions (telepresence robots, virtual agents)?

2 Literature Review

2.1 Social Presence through Telepresence Robots and Virtual Agents

A telepresence robot is a remote-controlled movable wheeled device equipped with cameras, speakers, microphones, a screen, and other interactive features for communicating and collaborating remotely [13]. A telepresence robot is an embodied agent of a physical body, whereas a virtual agent lacks a physical presence and requires users to access VR for communication and interaction. A virtual agent is a simulated character that socially interacts with the user to facilitate learning [14].

Both telepresence robots and virtual agents have potential applications to enhance students' social presence, improving the quality of interaction. Social presence refers to the subjective experience of being present with a 'real' person and having access to their thoughts and emotions [15], and it can be influenced by contextual and individual factors that impact perceptions of the psychological distance between interactants [16].

However, the approach to enhancing social presence differs between telepresence robots and virtual agents. Li (2015) reviewed 33 experimental works comparing how people interacted with physical robots and virtual agents. This review demonstrated that the robots were more persuasive and perceived more positively when physically present in a user's environment than when digitally displayed on a screen [17]. Physical robots elicit more favorable social responses than virtual agents to perceive a shared affordance space [18].

Although telepresence robots, by occupying the same physical space as users, may seem more advantageous in enhancing social presence compared to virtual agents, evidence suggests that virtual agents can be more effective than telepresence robots. If a virtual agent appropriately reproduces cues, behaviors, and content of speech that are socially realistic in real-world human-human interaction, it is considered to have high functional social fidelity, regardless of its physical embodiment. Further, some aspects of social fidelity (e.g., personalized language and politeness) are promising means of improving learning transfer and social presence [14]. In summary, telepresence robots enhance learners' social presence through physical embodiment, while virtual agents do so through high social fidelity.

2.2 Embodied Interaction through Telepresence Robots and Virtual Agents

Embodied interaction is defined as a model of interaction design that extends recent human–computer interaction (HCI) research trends in 'tangible' and 'social' computing [19]. Dourish characterizes embodied interaction by how the coupling of mental faculties and physical actions, combined with the social and environmental context, influence the creation, manipulation, and sharing of natural and meaningful interactions with technology [19]. The extended interface functions enabled by digital technology allow users to interact with computers in a naturally and physically expressive manner [20]. Such embodied interactions can address the limitations of traditional simulations, which often rely on highly abstract representations or limited feedback, by allowing learners to use more physical and expressive bodily inputs [21].

Several studies demonstrate the positive effects of embodied interaction in learning. For example, a mixed-reality simulation that involved full-body movements such as walking and running contributed to increased knowledge, self-efficacy, and engagement compared to a desktop version of the simulation [21]. In computer game design, an increase in body movement showed improvement in the player's engagement. Furthermore, an increased involvement of the body can afford the player a stronger affective experience [22]. Embodied interaction does not necessarily require full-body movements: different movement-based techniques such as finger walking in place (FWIP) can provide ease of navigation and enhance the effectiveness of spatial learning. In conclusion, when applying embodied interaction in learning, it is important to not only increase learners' physical movements but also to encourage natural movements by considering the learning context and the convenience of the learners.

3 Methods

3.1 Design-Based Research

Research-based design (RBD) is a systematic methodology that integrates theoretical insights with empirical evidence to develop educational content and technologies. This study employs RBD to design and evaluate learning companions in distance learning environments.

3.2 Procedure

The research-based design process involved the following phases:

Table 1. Procedure.

Process	Description
Extraction design principle	Theoretical frameworks of social presence and embodied interaction informed the initial design principles.
Prototype Development	A prototype of learning content incorporating telepresence robots and virtual agents was created.
Evaluation and Refinement	The prototype was reviewed by domain experts, and empirical insights were collected to refine the design.

4 Result

4.1 Extraction of Design Principles

The design principles extracted from social presence theory and embodied interaction theory to discuss the roles of telepresence robots and virtual agents are as follows (see Table 2).

Table 2. Design principles and roles of learning companion.

Design principles	Roles of learning companion	
	Telepresence robot	Virtual agent
To increase social presence, strengthen physical presence and physical embodiment.	Support tasks that require learners to move through the same space as the learner and allow learners to learn through movement.	
To increase social presence, strengthen interaction with high social fidelity of learning companion.	Provide feedback on learner responses through nonverbal interaction	
	e.g., nodding.	e.g., facial expressions, gestures, and body language.
To increase embodied interaction, it needs to increase not only learners' physical movements but also natural movements.	Provide support and feedback along the way so that learners can make the necessary movements in a real context.	

First, to enhance social presence, learning companions should reinforce physical presence and embodiment. Both telepresence robots and virtual agents can move within the learner's environment to support learning through physical movement. Telepresence robots can operate in both physical and virtual settings, while virtual agents are limited to virtual environments. Second, to further enhance social presence, learning companions should promote high-fidelity non-verbal interactions. Telepresence robots can adjust their panels to simulate nodding or shaking motions, whereas virtual agents can mimic a wide range of human-like interactions, such as facial expressions, gestures, and body language, within virtual environments. Third, to increase embodied interaction, it is essential to design learning activities that encourage learners' physical movement. The actions of telepresence robots and virtual agents should be context-driven and natural.

4.2 Prototype Development

A prototype was developed for a university laboratory safety training module. Using the station rotation model, learners engaged in multiple stages, including hazard assessment, emergency communication, and protective equipment use (see Figure 1).

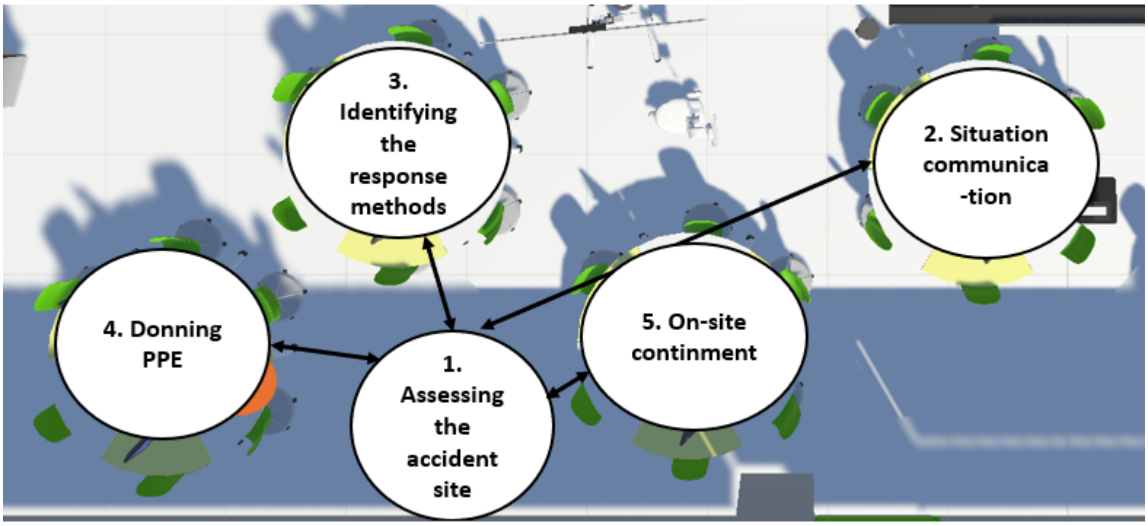

Fig. 1. Stations rotation for learning tasks.

Learning Task. The participants were university students, and the task was set in the context of a university laboratory. The objective of the task was to respond swiftly and accurately to an accident involving the spill of hazardous chemicals in a laboratory, from the perspective of a safety manager. This scenario is based on the Laboratory Safety Management Emergency Response Manual provided by the Korea National Research Safety Information System [23]. We applied the station rotation model to help participants focus on a particular activity rotation at each station (see Fig. 1). The task consists of four procedures: 1. Assessing the accident site, 2. Situation communication, 3. Identifying the response methods, 4. Donning personal protective equipment, 5. On-site containment. Materials and equipment required at each stage were placed at designated stations, and participants moved between the stations to complete the tasks.

Learning Companions. The roles of the learning companions based on the procedures of the learning task are outlined in Table 3. Their roles include assisting the learners in solving problems, for instance, guiding the station and offering hints/cues, feedback to learners, and non-verbal responses.This content has been designed for use in both physical and VR environments, with telepresence robots or virtual agents assigned the role of learning companions in each setting to support the learner's experience. The telepresence robot used in this study was developed by OhmniLabs and is equipped with features for communication and interaction, such as a microphone, speaker, and motor drive. The virtual agent, represented as an adult female character, is based on a model created by "Ready Player Me" and includes a locomotion animator feature. The VR environment, constructed in "SketchUp" to replicate real-world dimensions and layout, incorporated a telepresence robot captured with LiDAR technology, which was converted into a 3D object and imported into the VR environment. All interactions within the VR setting were developed using "Unity" version 2022.3.40f1.

Table 3. Task procedures and roles of learning companion.

<table>
<tr><th rowspan="2">Task procedure</th><th colspan="2">Roles of learning companion</th></tr>
<tr><th>Telepresence robot</th><th>Virtual agent</th></tr>
<tr><td>1. Assessing the accident site</td><td colspan="2">1.1. Assist the learner in assessing the accident site.
1.2. Help identify hazardous materials.
1.3. Support communication of the situation.
1.4. If the learner struggles with interpreting pictograms on warning signs, guide them to the pictogram explanations in the MSDS.</td></tr>
<tr><td>2. Situation communication</td><td colspan="2">2.1. Evacuate the accident site with the learner and communicate the situation.
2.2. Assist the participant in reporting the incident to emergency services.
2.3. Instruct the participant to mention the accident location and chemical substances when reporting to emergency services.</td></tr>
<tr><td>3. Identifying the response methods</td><td colspan="2">3.1. Review the response methods for hazardous material spills with the learner.
3.2. If the learner has difficulty finding the necessary response methods in the MSDS, the robot/agent provides hints or cues.</td></tr>
<tr><td>4. Donning personal protective equipment</td><td colspan="2">4.1. Confirm the required personal protective equipment (PPE) for handling the accident site with the learning companion.
4.2. If the learner struggles to find or wear the appropriate PPE, the robot/agent assists by offering hints or cues.</td></tr>
<tr><td>5. On-site containment</td><td colspan="2">5.1. Confirm the tools required for removing the chemical substance with the learning companion.
5.2. If the learner struggles to perform the task of removing the chemical substance using the appropriate tools, the robot/agent assists by providing hints or cues.</td></tr>
</table>

4.3 Evaluation and Refinement

To evaluate the effectiveness of the design principles, an empirical study was conducted involving both expert review and learner feedback. Two researchers specializing in educational technology assessed the design principles in terms of their applicability to learning content and the defined roles of the learning companions.

5 Discussion and Conclusion

5.1 Distance Learning Content Based on the Design Principles

We developed the prototype for distance learning by applying design principles supposing the situation to respond and contain an accident involving the spill of hazardous chemicals in a laboratory. This content was designed based on the station rotation model to make learners continuously move between stations that represent each task. The principle of embodied interaction is reflected in the design of this station rotation model. Moreover, to improve learners' social presence, telepresence robots and virtual agents support learners in performing tasks by acting as learning companions. Telepresence robots and virtual agents move to guide the learner through the learning process. Further, they give social feedback with their gestures such as nodding or shaking the panels or head to respond to learners.

5.2 Conclusion

This study has proposed design principles for the roles of telepresence robots and virtual agents as learning companions, grounded in the theories of social presence and embodied interaction. Through a design-based research approach, we developed a prototype of distance learning content that integrates these technologies to support learners in both physical and virtual environments.

Our findings indicate that telepresence robots, with their physical presence and embodied interaction capabilities, are particularly effective in enhancing social presence in physical settings. On the other hand, virtual agents, which offer sophisticated non-verbal cues in virtual environments, contribute significantly to creating human-like interactions and increasing learner engagement. Both learning companions, when applied according to their unique affordances, can reduce feelings of isolation and improve learner interaction in remote education settings.

The design principles we established provide a foundation for the development of more interactive, immersive learning experiences. These principles emphasize the importance of selecting the appropriate learning companion based on the learning context—whether physical or virtual—and tailoring their roles to enhance social presence and embodied interaction.

Further research is encouraged to refine these principles, explore their application in diverse educational contexts, and evaluate the long-term impact of telepresence robots and virtual agents on learning outcomes. Ultimately, this study contributes to the growing body of knowledge on the integration of advanced technologies in education, offering practical guidelines for future innovations in distance learning design.

5.3 Limitations

The limitations of this study lie in its application of only the initial stages of design-based research. While the prototype was developed based on design principles extracted from existing theories, it has not yet undergone usability testing or expert review. Additionally, further iterations of design and content application, such as the second and third cycles of refinement, have not been conducted. Future research will focus on advancing this work by detailing the complete design and development process.

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