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A Comparative Study of Presence and Simulator Sickness in Virtual and Augmented Reality Educational Environments

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A Comparative Study of Presence and Simulator Sickness in Virtual and Augmented Reality Educational Environments

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Abstract

Presence has been indicated as a critical factor in educational immersive environments, contributing to students' engagement and meaningful learning. This study examined the sense of presence and simulator sickness within an educational environment simulating electromagnetic waves in both immersive Augmented Reality (AR) and Virtual Reality (VR). Temple Presence Inventory and Simulator Sickness Questionnaire were administered to 47 undergraduate students who experienced the two immersive environments. Results showed that students reported in both AR and VR high levels of sense of presence, with significantly higher presence in VR. Simulator sickness showed low levels in both AR and VR, whereas VR noted significantly higher levels of sickness compared to AR. The results of this study are useful for the design of educational environments that utilize AR and VR technologies and highlight the importance of balancing presence and sickness when designing effective immersive learning environments. Further research is needed to examine how presence is affected in AR environments designed in a contextually meaningful way.

Keywords: Augmented Reality, presence, simulator sickness, Virtual Reality

Introduction

Presence was highlighted as one of the main features of virtual environments by Bricken (1990) when he proposed virtual environments for learning. Presence is described as the user's "sense of being there", in the virtual environment as a separate entity, feeling detached from the physical world (Slater & Wilbur, 1997). In AR, presence refers to the user's perception that virtual objects are integrated into their physical world in a coherent and contextually meaningful way (Billinghurst et al., 2015). Usually, presence is categorized into spatial presence, social presence and cognitive presence (Tran et al., 2024).

Immersion and presence are closely related in VR and AR technology, but they represent distinct concepts. In VR immersion refers to technology, how rich and multi-sensory the environment is described by the technological features of the system, such as field of view, display resolution, head tracking, interactivity whereas presence is about the psychological effect, how deeply the user feels immersed in the virtual world. In AR, immersion refers to how effectively virtual objects are integrated into the real environment, and how engaging, responsive, and sensory-rich the overall experience is. It is not about making the user detached from the real world (as in VR), but about how realistic the AR environment is with the virtual objects (Abbey et al., 2021; Billinghurst et al., 2015; Choi et al., 2019; Craig et al., 2009). Studies show that high levels of immersion lead to a stronger sense of presence.

There is growing evidence that presence positively influences learning in VR and AR. Presence in both AR and VR educational environments is a critical factor enhancing engagement, interactivity, and learning outcomes. In AR, presence contributes to a higher level of attention, curiosity, and exploration by integrating virtual object into the real world in a meaningful way (Cheng & Tsai, 2013; Radu, 2014), which could lead to conceptual understanding. Similarly, in VR, presence can enhance conceptual change, interaction, active knowledge construction and retention through high sensory immersion (Mikropoulos, 2006; Mikropoulos & Natsis, 2011; Slater & Wilbur, 1997; Witmer & Singer, 1998). In both AR and VR, presence enhances learning effectiveness, and designing immersive educational environments that foster presence can significantly improve learning outcomes. Regarding presence, previous literature review (Mikropoulos & Natsis, 2011) suggests that younger users often report a higher level of presence in VR environments.

Simulator sickness is a form of motion sickness which is caused by sensory conflict in immersive environments. Simulator sickness can negatively affect learning outcomes in both VR and AR contexts. Symptoms such as nausea, dizziness, eye strain, and disorientation reduce learners' comfort, limit attention and decrease engagement with the educational content (LaViola, 2000; Rebenitsch & Owen, 2016). In VR, where users are fully immersed, simulator sickness can significantly disrupt concentration and task performance. Learners may rush through tasks, limit exploration, or lose motivation to continue to avoid discomfort (Sharples et al., 2008). In AR, sickness occurs when there are inconsistencies in tracking, lag, or virtual object movement not aligned with the real world (Chang et al., 2020). In both AR and VR, simulator sickness can reduce the overall effectiveness of immersive learning experiences (Makransky et al., 2019).

Related work

This section presents studies that compare presence and simulator sickness in AR and VR environments by using Head Mounted Displays (HMDs).

In the study conducted by Jin et al. (2024), participants used immersive AR and VR environments for museums (the same application was used in both technologies). The results indicated that both technologies were considered suitable for enhancing effective learning in the context of museums. However, the experience in VR showed significantly higher levels of immersion, including concentration, empathy, and emotional engagement. Also, the participants in VR were more willing to engage in similar activities in the future. Gronowski et al. (2024) investigated the impact of presence on performance and user experience in VR and AR, regarding data visualization tasks, while using HMDs. VR was reported to provide higher levels of presence than AR, as it provided higher levels of realism, as well as increased efficiency and effectiveness in data visualization tasks. In Zhou et al.'s (2024) study, participants experienced AR and VR environments for immersive analytics using HMDs. The results showed similar feedback regarding presence experience. However, participants showed more tolerance to handle mentally demanding tasks when they were in the VR environment compared to the AR. Regarding navigation, more walking was reported in VR while further travel distance was found in AR. Huang et al. (2019) compared immersive AR and VR environments concerning science education. VR elicited greater levels of spatial presence and engagement, but AR was less cognitively demanding.

Ahmed et al. (2024) compared AR and VR using the same headset to assess simulator sickness, engagement, mental workload, and performance. The study found that users experienced higher simulator sickness in VR than in AR, despite similar levels of motivation and user experience.

The available studies are very limited, indicating the need for more research. Regarding the studies mentioned above, they report that VR shows higher levels of presence and simulator sickness compared to AR in educational applications. However, in most of the studies, in the AR environment virtual objects were not integrated in an authentic learning context. For example, visualized data, solar system—space museum were represented as superimposed digital objects in a room, which does not indicate an integration that would be expected to happen in the real world. Taking into consideration that one of the key aspects of presence in AR environments is that digital content should be meaningfully related to the user's real-world setting and that presence is strongest when virtual content is contextually and spatially aligned with the real world, making users believe that the augmented elements belong there (Billinghurst et al., 2015), the absence of studies applying these key aspects reveals a critical gap in understanding how such contexts influence presence and simulator sickness in AR environments.

Aim of the study

The aim of the study was to address the gap mentioned previously by comparing the sense of presence and simulator sickness experienced by participants in immersive AR and VR educational environments, designed in a coherent and contextually meaningful way, using HMDs.

Methodology

The empirical study was divided into four parts: an AR experiment, a corresponding questionnaire, a VR experiment (which simulated the AR environment), and the completion of the same (adjusted) questionnaire for VR. Quantitative analysis was performed using descriptive statistics and relationships between the variables in the AR and VR questionnaires were examined.

Participants

The sample was 47 undergraduate students from the Department of Primary Education, University of Ioannina, Greece. All students were in the last semester of their studies. During the experimental procedure, the students had just completed the course "Project Development with Emerging Learning Technologies", as part of their undergraduate curriculum. The gender distribution was predominantly female (83%), and the average age of participants was 24.1 years. Participants reported above-average computer experience and moderate experience with video games, VR, and AR technologies.

Research Procedure

The educational material used in the study was designed, ensuring that both the AR and VR environment reflected an authentic learning context, that is, it referred to a context that could plausibly occur in the real world.

Both AR and VR applications visualized the propagation of electromagnetic waves emitted by everyday devices. A cell phone, a DECT phone, a laptop and a router were placed in specific locations of the physical and the VR environment (Figure 1). The applications were developed using Unity 3D and C#. The AR experience was delivered through Magic Leap 1 glasses, while the VR through an Oculus Rift S (Figures 2 to 4).

Figure 1. Physical environment of the AR application (left) and VR application (right)

Figure 2. Electromagnetic waves expanding from laptop (left) and from all the devices at the same time (right) as virtual objects in the physical environment of the AR application

Figure 3. Electromagnetic waves expand from laptop (left) and from all the devices at the same time (right) as virtual objects in the physical environment of the VR application

Figure 4. A participant during the AR activity wearing the AR headset (left) and during the VR activity wearing the VR headset (right)

Each student experienced both AR and VR environments, where they could interact with digital objects by turning the emitting devices on and off (Fig. 2, 3, 4). During the procedure, each participant was standing up and free to move around the room. After turning on each device, the researcher asked the participant to describe what they were observing. After each activity, participants completed a questionnaire assessing the sense of presence and simulator sickness.

The experimental procedure, AR activity, AR questionnaire, VR activity and VR questionnaire, lasted about 40 minutes per participant.

Half of the participants (23 out of 47) did the AR activity first, then filled the AR questionnaire, followed by the VR activity and the VR questionnaire, whereas the other half (24 out of 47) did the VR activity first, then filled the VR questionnaire, followed by the AR activity and AR questionnaire.

Data collection

Sense of spatial presence was measured using the Temple Presence Inventory (TPI-SP), which uses a 7-item 7-point Likert scale (Lombard et al., 2009), and simulator sickness was assessed using the Simulator Sickness Questionnaire (SSQ), a 16-item 4-point Likert scale (Kennedy et al., 1993).

Data analysis

Data was analyzed using descriptive statistics. Paired-samples t tests were conducted to examine differences in the variables between AR and VR conditions. Simulator sickness scores were calculated according to the standardized formulas of the Simulator Sickness Questionnaire (Kennedy et al., 1993). Specifically, raw scores for Nausea, Oculomotor, and Disorientation subscales were computed and weighed using the recommended multipliers, and a Total Sickness score was derived using the established formula.

Results

This section presents the results on sense of presence and simulator sickness experienced by participants in AR and VR educational environments.

Table 1 presents the descriptive statistics of the TPI-SP questionnaire for the AR and VR environments. In both AR and VR, participants reported a high sense of spatial presence, indicating that both environments were successful in creating immersive learning experiences. Mean scores were higher in VR, suggesting a possible trend toward a greater sense of presence in VR compared to AR.

Table 1. Descriptive statistics for Spatial Presence in AR and VR conditions

Condition	Mean	Std. Deviation
AR	4.40	1.35
VR	5.53	1.02

Regarding simulator sickness, Table 2 presents the results from SSQ regarding the AR and VR environments. On average, participants reported relatively low simulator sickness scores in both the AR and VR conditions. Nevertheless, scores were consistently higher in the VR condition across all subscales and the total sickness score.

Table 2. Descriptive statistics for Simulator Sickness in AR and VR conditions

Variable	AR Mean	AR SD	VR Mean	VR SD
Nausea (N)	3.05	9.14	6.09	11.33
Oculomotor (O)	8.06	11.55	15.16	18.16
Disorientation (D)	10.66	14.86	20.73	25.61
Total Sickness (TS)	8.04	11.19	15.44	18.86

Comparing spatial presence and simulator sickness in AR and VR

Paired-samples t tests were conducted to compare presence and simulator sickness in AR and VR conditions based on participants' experience. Results showed that presence was significantly higher in VR (M = 5.53, SD = 1.02) than in AR (M = 4.40, SD = 1.35), $t(46) = -5.64$, $p < .001$, Cohen’s d = 0.82, indicating a large effect size. The results are presented in Table 3.

Table 3. Results of paired-samples t test for spatial presence (AR vs. VR)

Comparison	$t(46)$	p	Cohen’s d
Spatial Presence AR vs VR	-5.64	< .001	0.82

Table 4. Results of paired-samples t tests for simulator sickness (AR vs. VR)

Variable	$t(46)$	p	Cohen’s d
Nausea (N)	-1.75	.087	0.26
Oculomotor (O)	-3.12	.003	0.46
Disorientation (D)	-3.25	.002	0.47
Total Sickness (TS)	-3.11	.003	0.45

Paired-samples t tests confirmed that VR induced significantly greater oculomotor symptoms, disorientation and total sickness, compared to AR (Table 4). The nausea subscale did not differ significantly between conditions. Effect sizes indicated medium differences for oculomotor, disorientation, and total sickness.

Discussion

The aim of the study was to compare the sense of presence and simulator sickness of participants in VR and AR educational environments using head-mounted displays (HMDs) in an authentic learning context. According to the results, both VR and AR showed high scores of presence. However, in VR there were significantly higher responses. Participants in the VR environment experienced a higher level of presence, indicating that the sense of immersion was more effectively achieved in the virtual environment.

The above results may indicate that VR could create environments where participants could experience a higher sense of presence, likely due to its fully immersive nature that simulates the real world. In contrast, AR superimposes digital objects into the real environment, making the realism of the graphics used for the objects, a crucial factor for the sense of presence, as it is harder to make the combination of the real environment and the digital objects in a realistic way. However, all the presence scores were relatively high, which indicates that both AR and VR seem suitable for immersive learning.

Simulator sickness was reported at low levels in both AR and VR, showing that participants were able to engage with both environments without feeling important discomfort. However, results showed that VR had significantly higher values in total sickness, oculomotor symptoms and disorientation. This could be, as VR is a fully immersive technology and thus could lead to higher discomfort, as users are totally disconnected from the real environment. In contrast, AR contains real world context, which may help to experience reduced discomfort. Significantly higher sickness levels in VR indicate that the higher level of immersion may lead to greater simulator sickness. This suggests that during the design of VR in educational context, careful consideration should be taken to balance immersion with the risk of simulator sickness.

Similar findings have also been found in previous studies which examined the sense of presence and simulator sickness in immersive AR and VR educational environments (Ahmed et al., 2024; Gronowski et al., 2024; Huang et al., 2019; Jin et al., 2024; Zhou et al., 2024).

Conclusion

The results of this study are useful for the design of educational environments that utilize AR and VR technologies. The study demonstrates that both AR and VR technology can foster a strong sense of presence in educational settings, though VR showed significantly higher levels of spatial presence. These differences suggest that VR may offer a more immersive experience, particularly in interactive contexts. However, the higher level of sense of presence went along with a higher incidence of simulator sickness. These findings show the need to pay attention to the level of immersion so that the simulator sickness will not be increased and suggest that also other factors may be taken into consideration for the choice of AR or VR in the educational context, such as age, familiarity with technology and learning context.

Limitations and future work

This study offers insights into the sense of presence and simulator sickness in educational environments using AR and VR technology. However, several limitations should be mentioned. First, the sample included participants that were university students, which may limit applicability to younger learners. Future research should focus on K-12 students, whose familiarity with AR and VR and sense of presence could differ significantly.

In addition, although the AR application was designed based on an authentic context, further research is needed to compare the presence between authentic and non-authentic AR environments. If and how authentic context influences presence and learning engagement, could guide to more effective AR design.

Future research could examine the impact of transitions between AR and VR within the same student activity, investigating how shifting between AR and VR affects presence and engagement.

In addition, embedded assessment tools into the environments and students' activities would allow a more direct evaluation of the learners' sense of presence at the time of the learning process. These could influence their responses compared to answering after the AR and VR activities.

By addressing these limitations, future research could indicate the ways AR and VR environments should be designed to achieve a higher sense of presence among learners and thus improved learning outcomes.

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