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Evaluating Mixed Reality Collaborative Learning Environments: the MiRTLE+ Case Study

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Abstract. The rapid increment of using advanced technologies such as smart glasses, handheld and head-mounted devices have recently shown its efficiency and effectiveness in education. This paper uses MiRTLE+ model as a case study to evaluate the concept of mixed reality game involving remote and local learner in collaborative learning spaces. This aims to measure presence, immersion and learning outcomes. Four different learning game scenarios with two level of player background (Novice and Expert) were conducted using UNO game card. The results showed that learners presence and immersion in MiRTLE+ were significantly different from the presence and immersion of learners using traditional web-based platforms and very close to those of the control group who do not use technology.

Keywords: Human-Computer Interaction · Mixed Reality · Augmented Reality · Presence · Immersion · Learning Outcomes · Cards Games.

1 Introduction

In the Human-Computer Interaction (HCI) field, factors like presence and immersion have been studied theoretically and empirically to prove the effectiveness of mixed and augmented reality technologies for end users in such diverse sectors as health [3], military [9] and education [7]. In education, most of these empirical studies (e.g. [2] and [15]) have focused on measuring the impact of the aforementioned factors on students' interactions with their learning content. However, very few empirical studies have explored the effectiveness of these factors in relation to groups of students doing learning activities within collaborative synchronous mixed reality learning spaces. Learners and teachers using virtual environments typically have very limited interactions with their real teaching environments and the people within them. Thus, this case study focuses on developing and increasing the interactivity among remote virtual and real students in teaching environments. So far, however, there has been little investigation into

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how to increase the interactivity of remote virtual students in physical smart spaces based on the dynamics of interconnecting physical people and objects with their virtual counterparts.

In a previous paper [1], we proposed the MiRTLE+ architecture. It is considered to support the collaboration of small groups of people from different levels of background (i.e. novices and experts) and from different locations (i.e. distance and local) around learning tasks using mixed reality, augmented reality and virtual reality concepts, which makes its model design unique comparing to other mixed-reality approaches. Thus, the MiRTLE+, as it will be called in this paper, was developed into phases. In this case study paper we consider to explore the impact of different learning scenarios by using different interface devices (i.e. the use of tablets and PC screens), whereas the next phases will consider immersive augmented reality glasses and virtual reality head-mounted display in the future work.

Four different learning scenarios are structured based on user interfaces, locations (remote and local) and levels of expertise (novice and expert) as shown in Fig 1.

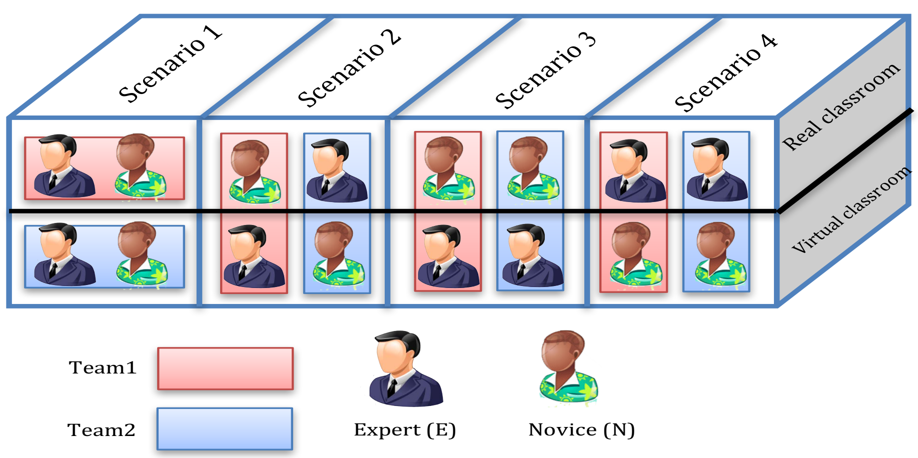

Fig. 1: Learning scenarios of phase one.

Moreover, the MiRTLE+ learning scenarios will be compared with our baseline control group (i.e. participants who will not use technology at all) as well as the web group (i.e. participants who will use a 2D web browser and Hangout software for collaborating in the learning activity).

In the following, we discuss this further, in six parts. The following part describes the background and related work. In the third part, the experimental approach and design are presented. The fourth part will demonstrate the results and analysis. Then, our results are discussed in the fifth part. Finally, the conclusion will be drawn.

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1.1 Research questions

Independent variables for our research questions in this paper are considered to be learning scenarios and users interfaces. Thus, this study will address the following research questions (RQs):

1. What are the differences of learning effectiveness depending on which learning scenarios or users' interfaces are used?
2. What are the differences of participants' sense of presence and immersion factors depending on which learning scenarios and users' interfaces?

2 Background and Related Work

2.1 Mixed Reality(MR)

Mixed reality (MR) (also called hybrid reality) is the merging of virtual and real worlds to create new spaces that accommodate and visualise virtual and real objects in real time and enable users to interact with them [16]. Milgram and Kishino [12] also define MR as a generic concept within the zone between real spaces and immersed virtual spaces. This zone is where graphical computer based objects exist in real space (augmented reality) and where real objects exist in virtual space (augmented virtuality), as shown on the Reality-Virtuality Continuum in Fig 2. The MR concept can be used as an advanced tele-presence method to connect the virtual environment with the physical environment [14].

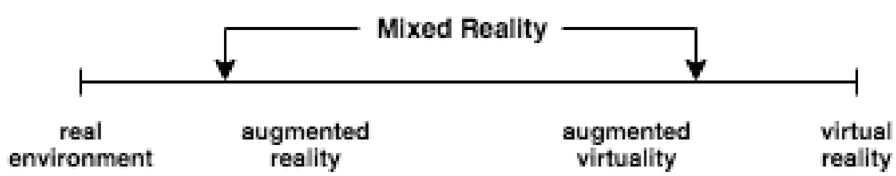

Fig. 2: Reality-Virtuality Continuum.

One another example of applying the concept of MR is the MiRTLE project. The MiRTLE (which was developed by the university of Essex [6]) was empirically designed using the Open Wonderland project, which is a popular open source software tool for creating 3D virtual spaces. The Open Wonderland project is a Java-based system that provides a purpose-built world targeting education, business and government applications. The MiRTLE project basically sought to allow remote students to virtually (in a 3D environment) interact with local students and their teacher. The system allows remote students to share programs, such as word processors and Internet browsers. The remote students' presence takes the form of avatars superimposed with their login names as shown in Fig 3.

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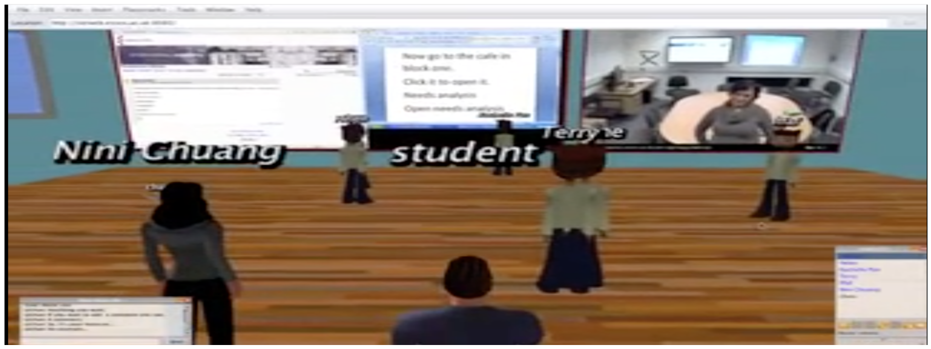

Fig. 3: MiRTLE avatars superimposed with their login names.

3 Experimental Approach

3.1 Subjects

Twenty-four participants voluntarily participated in the experiment, of which 16 participants were to use the MiRTLE+ platform, four participants were to use the web platform, and four participants were to be the control group. The participants were recruited from the University of Essex through an opportunity sample and signed a consent form. Twelve participants who had never played the Uno card game and did not know its rules were recruited as novices. Another 12 participants who had played Uno and knew its rules were recruited as experts. The participants were recruited in groups for our different learning scenarios. Each scenario had four participants playing in two teams. Each team had a novice and an expert player.

(a) Local participants, scenario 1 (b) A remote participant, scenario 1

Fig. 4: Participants in various MiRTLE+ learning scenarios

3.2 Tasks and procedures

We propose a simple learning activity task in which a group of students are asked to play a card game, which will have a number of rules and instructions. Usually,

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people prefer to learn these types of games by being able to practice with experts whilst playing a real game. In addition, the Uno card game is specifically selected because its rules are simple, and achieving the target does not take a long time, which fits with our experiments' time constraints.

During the setup phase with the participants, the pre-test for the Uno card game rules and the demographic questionnaire concerning each user's technology background were sent to participants via email and completed before starting any of the experiments. The experimenter assigned four participants, two experts and two novices, in each learning scenario based on their availability by using the Doodle website.

The Web learning scenario: For the web group, participants were also provided with instruction sheets. The instructions included the log-in procedures for the Hangout[4] application to enable a video call between participants. Also, it included how to start the game session through the web browser. Participants logged in from their office machines that were distributed around the university campus. One participant logged in from the iClassroom to follow up on the procedures established by the experimenter.

The control group scenario: The control group participants were all recruited to play the Uno card game on a table with four chairs in the iClassroom. They did not use technology at all. They were provided with a real Uno card game pack and instructions sheet (which included when they should discuss the game and the target to win the game). Experts were also given extra sheets for recapping the rules. Two video cameras were set up in the iClassroom to record novice participants play actions, the spent time for each session and discussions between the game rounds.

3.3 Data collection

Qualitative and quantitative data: Data for the main dependent variables (mentioned in the introduction of this section) were collected from (1) the Presence Questionnaire, together with the four factors related to presence identified by Witmer and Singer [17], namely, control, sensory, distraction and realism; (2) the Immersion Questionnaire (IQ), with its five factors identified by Jennett et al. [8], namely, control, challenge, real-world dissociation, emotional involvement and cognitive involvement; and (3) learning outcomes, which will be described further in the next paragraph.

Learning outcomes: In order to measure learning effectiveness, two methods were applied: pre- and post-tests for measuring participants' knowledge in playing the Uno card game and an error-based testing system to track novices playing as they played and learnt rules during the game task.

[4] https://hangouts.google.com/

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4 Results and Analyses

4.1 The experiment

As explained earlier, this study focused mainly on the differences between MiRTLE+ interfaces within various learning scenarios. Table 1 described the analysis of all scenarios. This table presents the means of all dependent variables (i.e. presence, immersion and learning outcomes) based on the interfaces used in each scenario by experts and novices.

Table 1: Descriptive statistics for scenario-based interfaces

	Scenarios interfaces comparisons									
	Scenario 1		*Scenario 2*		*Scenario 3*		*Scenario 4*		*Web*	*Control*
	r	*l*	*r*	*l*	*l*	*r*	*r*	*l*		
Presence	5.35	5.35	5.00	5.15	5.44	4.47	4.94	4.56	4.31	5.88
Immersion	3.88	3.88	3.88	3.82	3.92	3.90	3.86	3.98	3.51	4.24
Learning outcomes	10%	80%	30%	50%	45%	N/A	35%	N/A	35%	45%

Notes: r = remote users who used PC screen interfaces, l = local users who used iPad-based AR interfaces, N/A = not applicable for novices regarding the teaching variable or experts regarding the learning variable.

Scenarios comparison

Presence: The analysis revealed a statistically significant difference between the presence means in our scenarios determined by one-way ANOVA ($F(5, 18) = 4.055, p = 0.0122$). To follow up the ANOVA results, post hoc test was carried out using Tukey's HSD (honest significant difference) test in order to make a pairwise comparison. The results showed that the difference between control and web group was statistically significant at 0.01 and the difference between control group and scenario one was statistically significant at 0.1.

Immersion: The ANOVA test was also carried out to test differences in the immersion level among the scenarios. A statistically significant difference was found between the MiRTLE+ scenarios, web and control groups ($F(5, 18) = 2.924, p = 0.0419$). To follow up the multiple comparisons, the Tukey's HSD test was applied. The result showed that the difference between control and web group was statistically significant at 0.1.

Learning outcomes and scenarios differences: First, from the above table the learning gain scores that appear in percentage were quite similar among scenarios. However, scenarios 1, 2 and 3, in which novices used AR interfaces,

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present very convergent or similar scores (i.e. 45%, 40% and 45%, respectively) to the control group (45%), whereas the scores of novices who exclusively used VR PC screens (35%) were similar to those of novices who used the web scenario (35%). This could indicate that novices in scenarios that involve AR interfaces could have more knowledge gains than those in web or screen-based VR scenarios. However, as the difference was not statistically significant.

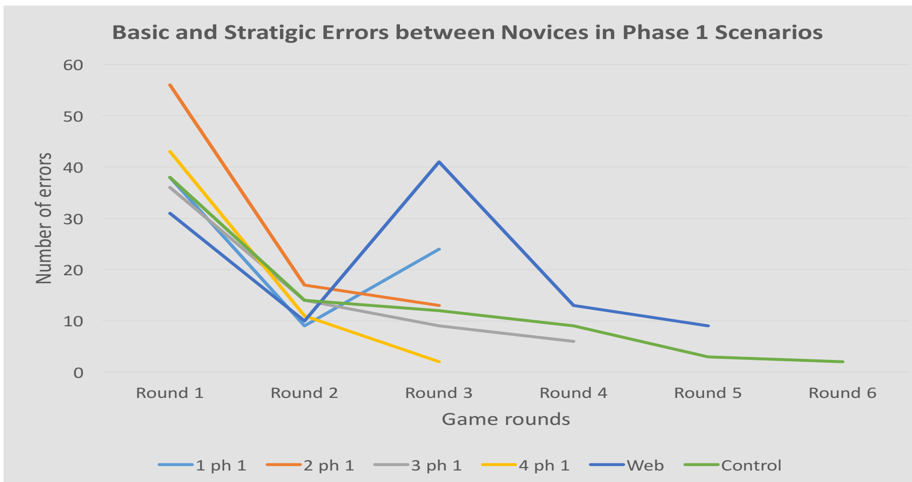

Fig. 5: Basic and strategic errors committed by novices in phase one scenarios.

By monitoring novices' errors from the database as shown in Fig5 below, we noticed that the number of novices' errors in most of the phase scenarios as well as the control group decreased from the first round to the last round (i.e. when the target is reached and the game is over), indicating that novices' knowledge of Uno rules improved with time. However, unexpected changes occurred in scenario 1 (i.e. 1 ph 1) and the web scenario. The participants' scores increased in round 3, possibly because of other factors (i.e. time, different cards and the novices' backgrounds).

Presence and immersion between scenarios: A deeper analysis was also carried out to reveal the differences between interfaces in the scenarios. As we defined in the above table, l stands for local users who used iPad interfaces, r stands for remote user who uses VR on screen-based interfaces, w is for the web platforms users through screen-based interfaces and c is for control group users (i.e. without using technology). We analysed the differences of presence and immersion variables between those four interfaces by using one-way ANOVA test as presented in the following table 2 on page 8 below.

The above table shows statistically significant differences among the interfaces for all three variables. To follow up, we applied the pairwise Tukey's HSD

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Table 2: ANOVA results for the study variables subjected to interfaces

	F	df	p-value
Presence	6.484	(3,20)	0.00449**
Immersion	5.321	(3,20)	0.00735**

* p <.05
** p <0.01

test and found a significant difference of $p < 0.01$ between c and w for the presence and immersion variables. Further, from the previous table 1 on page 6, the differences in means (with their standard deviations) for presence between the w interfaces 4.31(0.86) and the c group 5.88(0.11) were significant at 0.01, and the differences between the r interfaces 4.98(0.58) and the c group were significant at 0.05; in contrast, no significant difference was found between the c group and the l interfaces 5.12(0.40), indicating that the experiences of participants who used the l interfaces were closer to the c group than those who used the r interfaces.

5 Discussion

This section will discuss our results by answering the sub-questions RQ1, RQ2 and RQ3 which were reworded from our research questions presented earlier in the introduction.

RQ1: Is there a relationship between novices' learning outcomes and presence and immersion in phase one scenarios?
RQ2: Is there any difference in the participants' sense of presence and immersion depending on which learning scenario/activity is used?

Presence: The results demonstrate that participants felt spatially present in all MiRTLE+ scenarios (i.e. the virtual world and the augmented world), but did not perceive them as real. Surprisingly, a comparison of the mean scores showed a statistically significant difference between the web group and the control (real) group. However, the MiRTLE+ scenarios were not significantly different from either, although the means with their standard deviations were closer to the control group than the web scenario. This implies that experts and novices tended to be more present when they were interacted using AR and VR interfaces. One the experts explained this in the following words:

I used to play Uno in my iPad, but this experience is too creative. I can communicate with friends and can see their avatar which makes me feeling be there. Sometimes the sound is not clear but I still understand my friends.

A comparison of the presence means showed that the web interface was significantly different from the AR interfaces and the control group. That is, the web interfaces scored the lowest on presence, as originally hypothesised. Participants

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using the AR interfaces felt closer to reality than those who used normal PC screen interfaces. This empirical finding strongly supports the theoretical claim that the AR features of navigation, manipulation and sensory immersion might enhance the users feelings of presence [10]. Furthermore, a very strong positive correlation was observed between presence and novice learning outcomes, which supports this research outcome. De Lucia et al. confirmed that "presence and learning are strongly related: increasing presence also increases learning and performance" [4]. Witmer and Singer echoed this same sentiment saying, "it would be very surprising indeed if positive relationships between presence and performance were not found" [18].

Immersion: Similar results were found with immersion level in that a significant difference was found between web-based users and the users of AR-based interfaces as well as between web-based users and control groups. These results might imply that a more visual system interface with robust and interactive 3D graphics could elicit higher levels of immersion than an interface that is less visually attractive (i.e. when compared with the reality, the AR-based environments, the VR-based environments to the web-based platform). This supports the findings of [11, 8]. Furthermore, novices and experts using the same interface either an iPad or a PC screen (i.e. involving a similar 3D environment) reported similar feelings of immersion, as indicated by the similarity in their immersion means for the MiRTLE+ 4 scenarios. It is equally possible that participants in the VR and AR conditions were similarly distracted by the graphics as well as the novelty of the environment, and this may have cancelled out any difference in immersion levels between them.

RQ3: Is there any difference in novices' learning effectiveness depending on which scenario/activity is used?

Learning: In our experiment, novices within scenarios that involved AR interfaces had higher learning gain scores than those using the web-based platform or VE interfaces. Further, these scores were closer to that of the control group. Although the learning differences between the scenarios were not significantly different, possibly because of the mix of interfaces in each scenario, it is interesting to note that the AR-based interfaces led to better learning gains for novices than web-based interfaces. These findings seem to support this previous study [13].

A follow-up analysis of the novices' achievement in our error-based system showed a decrease in errors during the game rounds. This combined with the results of the pre- and post-tests validates the improvement shown by the novices in learning Uno rules. However, scenario 1 showed an increase in errors in round 3, although the it was less than round 1. Overall, this result may also be suggestive of an improvement in learning. A similar pattern was observed in the web-based group in round 3; however, the errors decreased dramatically after that round, suggesting high subsequent improvements. These achievement trends may be explained by different factors. Firstly, round 3 may feature new card scenarios

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that could be more difficult than those played earlier. Secondly, the playing time for round 3 was longer than that for the other rounds, which could generate new card game situations and support to the previous point. The third factor, which is also related to the time, is that the spent time on discussing Uno rules with the experts before each round needs also to be considered. In the web-based scenario, novices and experts had a longer time for discussion after round 3, which was not the case in scenario 1.

Given the longer playing time and discussion time before round 3 in scenario 1 and in the web-based scenario, it is likely that if this round was played before the other rounds, a decreasing trend, similar to the other scenarios, may have been witnessed. Nevertheless, according to Hamari et al. [5] learners hone their skills and build knowledge of the game rules (by decreasing the errors in our case) as long as they continue to play.

Although the results of the current study show significant differences between the study groups, some of them should be taken tentatively due to the relatively small sample size for some of these groups (e.g. grouping by scenarios). For this reason, while the results obtained from the interface and location can be said to be generalisable based on comparison with credited previous studies in the literature (e.g. [13]), those for grouping by scenarios should be interpreted rather cautiously as descriptive statistics without drawing further conclusions. Future research may consider focusing more closely on grouping by scenarios by repeating the experiment in each scenario.

6 Conclusion

This case study was produced to evaluate learners' presence, immersion and learning effectiveness by using our MiRTLE+ model. We found that novices using the MiRTLE+ learning scenarios showed better learning performance results and closer (although not significantly so) results to the control group than those using web-based platforms. Presence and immersion were positively related to learning outcomes in almost all learning scenarios. The participants' presence and immersion in MiRTLE+ were significantly different from the presence and immersion of participants using traditional web-based platforms and very close to those of the control group. Furthermore, the user interface played a key role in increasing and decreasing the levels of all mentioned factors to show that, compared to other VR and web-based variables, AR interfaces were highly considered to be the most influential variables to increase the users sense of presence and immersion, and their learning outcomes. We also concluded that although these technology interfaces are still under development and investigation, they have a high potential for effectiveness in learning through their application in collaborative MR learning spaces. However, we must also take into account their shortcomings (e.g. distractions while holding or cybersickness while wearing the interfaces), which continues to affect some users.

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