Towards the Development and Understanding of Collaborative Mixed-Reality Learning Spaces



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Abstract

The current era of advanced display technologies, such as head-mounted displays, smart glasses and handheld devices, has supported the usage of mixed reality and augmented reality concepts in smart educational classrooms. These advanced technologies have enabled enhanced collaborations and interactive communication between distance learners and local learners. Whilst being present, immersed and engaged are key factors in both the real and virtual worlds, they play particularly important roles in improving students collaborative learning performance during learning activities. However, few empirical studies have considered how using such interfaces may affect learning outcomes and whether students truly feel fully immersed and engaged in such environments. Furthermore, the lack of support and a conceptual architecture for collaborative mixed and augmented reality group learning activities is still a shortcoming for distance learning and teaching, and a significant challenge to researchers.

This study demonstrates a conceptual framework that supports group distance learning and teaching collaboration around learning activities using mixed, augmented and virtual reality technologies. The study also explores learning effectiveness based on the following factors: students presence, engagement and immersion in smart environments. To evaluate these factors, we utilise several existing frameworks that have been applied to our mixed reality platform, MiRTLE+, to help us examine the learning outcomes and teaching experience gained from using these environments.

The study was divided into two experimental phases, and 40 samples were examined to assess and compare the affordances of mixed reality interfaces within various collaborative learning scenarios, applying a card game activity (Uno) as a learning task. By comparing the real collaborative learning activities with the two-dimensional web-based activity, we found that novices had slightly better learning performance than the individuals using the web-based activity and that both phases mimicked reality. Novices and experts also felt significantly more present and immersed in the MiRTLE+ learning scenarios (due to the impact of the augmented reality interfaces) than in the web-based scenario.

To my parents . . .

To my wife . . . To my daughter and sons . . .

With warm love and full respect . . .

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Abbreviations

Terms	Description
MR	Mixed reality
VR	Virtual reality
AR	Augmented reality
AV	Augmented virtuality
MiRTLE	Mixed reality teaching and learning environment
MiRTLE+	Adapting AR in a collaborative mixed reality teaching and learning environment
CSCL	Computer-supported collaborative learning

Glossary

Terms	Description
Scenario	A group of 4 participants are formed based on their locations (local or remote), interface (tablet, AR glasses...etc) and level of expertise (novice and expert).
Phase	Participants are distributed based on user interfaces (i.e. by using tablet and PC screens in phase one and by using AR glasses and VR headsets in phase two).
Platforms	Participants are distributed based on platforms (i.e. MiRTLE+ platforms, control group and web platform).

Chapter 1

Introduction

Advances in 3D virtual environments and the use of such equipment as head-mounted displays, goggles and new smartphones can provide new opportunities for teaching and learning. Scholars and marketing have revealed that intelligent wearable glasses are likely to be the next 'big thing' in the scientific evolution [1]. These new technologies and environments can potentially lessen distant learners' sense of isolation [2] and allow students to communicate more naturally, with a greater sense of 'being there'. Some recent studies [3, 4] have used mixed-reality[1] concepts to achieve interactive communication between remote and local people in 3D virtual-reality environments. For instance, Gardner and O'Driscoll [6] and Schmidt et al. [7] found that representing remote students as avatars on a screen in a real smart classroom (e.g. iClassrrom[2] at University of Essex) could enhance the remote students' sense of engagement and increase their feelings of being there through virtual connections to their real teachers and fellow students.

In the Human-Computer Interaction (HCI) field, factors like presence, immersion and engagement 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 [8], so-

[1] It 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 [5]

[2] `http://ieg.essex.ac.uk/portfolio/iclassroom/`

ciality [9], military [10] and education [11]. In education, most of these empirical studies (e.g. [12] and [13]) 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 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 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. Furthermore, this research investigates the impact of this approach using different learning scenarios and with different immersive user interfaces and levels of user expertise in a game learning task. It also explores the implications on the learners' and experts' sense of presence, immersion, engagement, learning outcomes, teaching experience and user experience. In so doing, this research empirically explores the affordances of the use of these technologies for mixed and augmented reality[1] learning spaces compared to equivalent face-to-face collaborations in the real world and when using more traditional web-based platforms.

1.1 Motivation

Given advancements in mixed and augmented reality technologies, researchers are becoming more interested in applying these technologies to learning activities and exploring their effectiveness in improving learning performance and other psychological aspects, such as engagement. For example, Callaghan et al. [14] note that "Our longer term vision is to create an entire mixed-reality campus..." in order to provide distance learners the opportunity to

[1]It is a real-world (physical) environment whose elements are augmented by computer-generated sensory inputs, such as sound, video, graphics or GPS data

learn in a mixed-reality space that is merged with local learners' spaces and enhance their mutual sense of sociality. Mixed reality and augmented reality interfaces, such as the Oculus Rift headset, are rapidly evolving. Figure 1.1 on page 3 depicts examples of some of these modern technologies. The high usage statistics show high levels of investment and revenues in health, military, sociality, games and education [15].



Figure 1.1: Mixed and augmented reality interfaces

Therefore, the first motivation of this study is to empirically explore the affordances of these mixed reality interfaces for learners from different psychological (HCI) and educational perspectives in a collaborative mixed reality learning space from different geographical locations and with users of different levels of expertise. The second motivation is personal, since my current employer (i.e. University of Umm Al-Qura in Saudi Arabia), who sponsored me during my study in the United Kingdom, requires this research and development project to fall under the umbrella of pedagogy and technology.

1.2 Problem statement

This study is based on the original Mixed Reality Teaching and Learning Environments (MiRTLE) approach [16]. The MiRTLE is a lecture-based environment that enables the lecturer to see connected remote students as avatars through a big screen mounted on the

real classroom wall. The remote students, on the other hand, have two in-world screens which in turn provide them a view of the real classroom (i.e. the lecturer and real students) in one screen and the lecture content on the other screen. However, in this study, we extend the MiRTLE approach to explore more interactive and engaging techniques for merging local and remote learners within a collaborative real classroom setting. By using the augmented reality and mixed reality concepts within MiRTLE, we integrate remote students (via their virtual representations) more closely with their local (physically present) counterparts. In so doing, we hope to enrich the learning activities within the mixed reality learning environment and improve the collaboration and sharing between local and remote learners. The system is referred to as MiRTLE+. The MiRTLE+ approach 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. Thus, the MiRTLE+, as it will be called in this thesis, is divided into two phases to explore the impact of different learning scenarios by using different interface devices. Phase one considers the use of tablets and PC screens, whereas phase two considers immersive augmented reality glasses and virtual reality head-mounted display. In each phase, four different learning scenarios are structured based on user interfaces, locations and levels of expertise. For example, the scenario one in the phase one will involve two participants (expert and novice as a team) in the local classroom who will use tablets, and other two participants (expert and novice as another team) will connect remotely by using PC screens. 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).

1.3 Contribution

The main objective of this research project is to investigate the methodologies through which the use of mixed and reality spaces involving augmented reality technology in distance learning affects the learning processes that take place. What the potential for this technology is, and how they can be exploited in the classroom. Thus, this study considers two major contributions, as follows:

1. An architectural framework for experimental collaborative technology-enhanced learning spaces comprising mixed and augmented reality interfaces, mirrored virtual and physical objects, web-based shared activities and voice communication by extending the concept of MiRTLE and addressing the challenge of synchronising real and virtual objects.

2. To explore the use of different HCI interfaces in different learning scenarios in mixed and augmented collaborative learning spaces in order to increase learning performance by improving the learners sense of presence, immersion and engagement.

In addition, a number of secondary contributions appear during this research as follows:

1. The development of an error-based system built on the open-source Uno card game to enable experts and experimenters to keep track of novices' errors during the game.

2. The design and completion of a pre-design survey of experts' views concerning the Uno card game rules as validation for our error-based system rules.

1.4 Research questions

Independent variables for our research questions are considered to be learning scenarios, platforms and phases for this study as explained in section 1.2 on page 3. Thus, this study will address the following research questions:

1. What are the differences of learning and teaching effectiveness depending on which learning scenarios, phases or platforms are used?

2. What are the differences of participants' sense of presence, immersion, engagement and users experience factors (as they will be described in section 5.1 on page 103) depending on which learning scenarios, phases or platforms are used?

3. What are the relationships between participants sense of presence, immersion and engagement with learning and teaching effectiveness depending on which learning scenarios, phases or platforms are used?

1.5 Hypothesis

My hypothesis consists of two statements that I will endeavour to prove by means of experiment and evaluation. First, it is possible to devise a conceptual architectural model capable of gathering a group of remote and local experts and novices into different learning scenarios, allowing them to exchange learning content in a collaborative, mixed-reality learning space. Second, in a range of collaborative augmented reality and mixed-reality learning application scenarios, the novices' learning performance with experts will increase because they experience a greater sense of engagement, presence and immersion, as well as achieve higher learning outcomes (these factors will be explained in details in section 5.1 on page 103). Furthermore, the experts' teaching experiences will result in a positive response to these technologies. Therefore, my study will include two phases. In phase one, novices and experts will use tablets and PC screens in local and remote spaces, respectively. In phase two, students and experts will use VR glasses in both extremes. Thus, I postulate that the novices' learning performance, experts' teaching experiences, and the users' sense of presence, immersion and engagement measurements in the first phase will be higher than those observed with traditional web-based applications but lower than those seen while learning in a face-to-face classroom. However, the measurements in the second phase are likely to be

quite similar to those seen in traditional classrooms and will probably be even higher than those observed with web-based applications.

1.6 Publications

Ahmed ALZAHRANI, Michael GARDNER and Vic CALLAGHAN, "A Collaborative Learning Game in an Augmented and Mixed Reality Space for Different Levels of Expertise," The 9th Saudi Students Conference (SSC), 2016.

A video demonstration of this study project in the BETT16, one of the biggest exhibitions for education and technology in the world. That was in London (20th - 23rd January 2016), the video link: `https://youtu.be/hJXNDuj_ZK4`

Ahmed ALZAHRANI, Michael GARDNER and Vic CALLAGHAN, "Using the Uno card game as a Measurable Learning Task in a Collaborative Augmented and Mixed Reality Learning Space," iLRN 2015 Conference, on Workshop, Short Paper and Poster Proceedings from the inaugural Immersive Learning Research Network Conference , p. 55, 2015.

Ahmed ALZAHRANI, Michael GARDNER, Vic CALLAGHAN and Malek ALRASHIDI, "Towards Measuring Learning Effectiveness considering Presence, Engagement and Immersion in a Mixed and Augmented Reality Learning Environment," iLRN 2015 Conference, on the Workshop Proceedings of IEEE 11th International Conference on Intelligent Environments 2015 (IE'15), IEEE Computer Society, Prague, Czech Republic, pp. 252 - 264, 2015.

Ahmed ALZAHRANI, Vic CALLAGHAN and Michael GARDNER, "Towards the Physical Instantiation of Virtual People and Components in Physical Mixed-Reality Tele-Presence

Environments," on the Workshop Proceedings of IEEE 10th International Conference on Intelligent Environments 2014 (IE'14), IEEE Computer Society, Shanghai, China, pp. 285-294, 2014.

1.7 Thesis outline

This thesis is divided into seven chapters and organised as follows:

This chapter **(Chapter one)** briefly introduces the trends of interest in this thesis, the motivation underpinning this study, the contributions and hypotheses to be investigated and the publications produced from this study.

Chapter two introduces related concepts and studies and discusses the research rationale of theoretical and empirical studies that have attempted to investigate the usability and benefits of mixed and augmented reality technology interfaces in different fields, and more specifically, in education from technical and pedagogical perspectives. The chapter ends with a summary of related studies and identifies the gaps/motivations which relate to this new research.

Chapter three introduces the areas of mixed reality, game-based learning and HCI covered in this thesis and describes the theoretical frameworks and pedagogical theories used to form our architectural model MiRTLE+. The chapter mainly covers one of the main popular mixed reality taxonomies (the Milgram taxonomy [17]) and related pedagogical theories of games, learning by card games and collaborative learning. Next, we describe how a theoretical framework based on the Uno card game activity as a game-based learning task was developed. The chapter ends with a summary of the technical and pedagogical factors that influence the conceptual and architectural model that have been developed as part of this research.

In **Chapter four**, the experimental framework is described. This chapter starts by explaining the learning scenario in this study. Next, it describes the development of our proof-of-concept MiRTLE+ platforms in two phases. Then, it discusses the expert identification of our game rules levels via a conducted pre-survey. In two phases, this chapter also explains the experimental design aspects: subjects; variables; apparatus and procedures; ending with a summary of all topics addressed in this chapter.

Chapter five presents the results and analysis of our experiments in two phases. In each phase, the results are presented by discusses the differences in learning outcomes, scenarios and interfaces in terms of the users sense of presence, immersion and engagement and the correlation with their learning outcomes. Next, the teaching experience results and the correlation with the learning outcomes are presented. Lastly, the user experience results across the different scenarios and interfaces are shown; ending with a summary of the overall results and an analysis of the groups, scenarios and interfaces for our dependant variables.

The results are discussed in **Chapter six**. This chapter presents a detailed, three-section examination of the first phase, the second phase and the general discussion between groups. The chapter also answers our research questions and ends with a summary of the overall vision, which supports our final discussion.

Finally, **Chapter seven** concludes this study and suggests future work. This chapter outlines overall achievements, answers our research questions and draws final conclusions regarding our empirical exploration of mixed-reality technologies from an educational perceptive. The chapter ends by discussing a number of future directions that could be investigated, but which fall outside the scope of this study due to time constraints.

Chapter 2

Related Work and Research Rationale

This chapter investigates the background and related studies of the research topic. It begins by defining the concepts of mixed and augmented realities, and then exploring their shortcomings in current frameworks and architectures for collaborative learning spaces, highlighting their importance and features in educational settings. This is followed by a description of the features and differences between virtual and augmented reality interfaces. Then, the chapter investigates the human-computer interaction studies related to psychological topics, such as engagement and presence, and explore their shortcomings to determine their effectiveness within collaborative mixed and augmented reality learning spaces. This chapter also addresses related pedagogical views, theories and frameworks. Finally, the chapter concludes by identifying the gaps and problems in related studies, which this research seeks to address.

We address related works of supporting small groups distance learning collaboration around learning tasks using mixed, augmented and virtual reality technologies. Furthermore, the chapter also considers the impact of different scenarios on the learning effectiveness. Therefore, we attempt to cover the areas of studies of the mixed reality, human computer interaction and learning and teaching theories as shown in figure 2.1 on page 11.

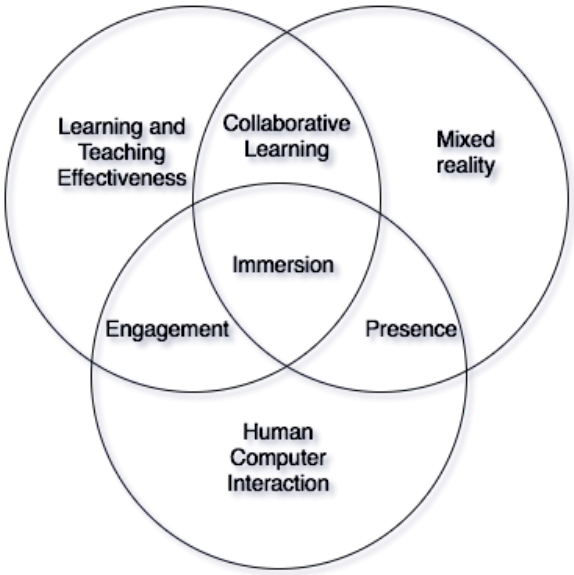


Figure 2.1: This study draws together the areas of mixed reality, human computer interaction, learning and teaching

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 [5]. Milgram and Kishino [17] 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 figure 2.2 on page 11. The MR concept can be used as an advanced tele-presence method to connect the virtual environment with the physical environment [18].

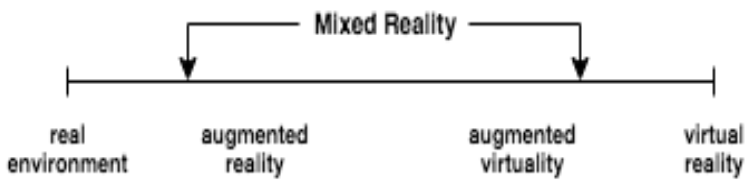


Figure 2.2: Reality-Virtuality Continuum [19]

The Mixed Reality Teaching and Learning Environment (MiRTLE), developed by the university of Essex [20], and the Holodeck system, developed by the University of Hawaii [7], are two examples of MR learning environments.

The MiRTLE project was empirically designed using the Open Wonderland project, which is a popular open source software tool for creating 3D virtual spaces [21]. The Open Wonderland project is a Java-based system that provides a purpose-built world targeting education, business and government applications.

The MiRTLE project 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 figure 2.3 on page 12 [6].



Figure 2.3: MiRTLE avatars superimposed with their login names

MiRTLE has been deployed in the iClassroom, which is a high-tech teaching environment at University of Essex. The iClassroom implementation comprises of speakers, microphones, and a voice-bridge (within the system) to enable voice communication between remote and local students. Furthermore, it includes an IP camera and a large display screen, both of which are components of MiRTLE. Thus, physical students can be viewed in the virtual

world screen through the IP camera, which is mounted on the iClassroom wall.

The virtual students are displayed in the real environment through the screen positioned at the rear of the iClassroom as shown in figure 2.4 on page 13. This screen allows the teacher and the real students in the iClassroom to see the virtual students in the lecture, as shown in figure 2.5 on page 13. In this figure, the left side is what the lecturer sees from the mounted screen on the real classroom, whereas the right side is what the view of these two avatars (students) in the virtual environment.



Figure 2.4: The real environment of MiRTLE

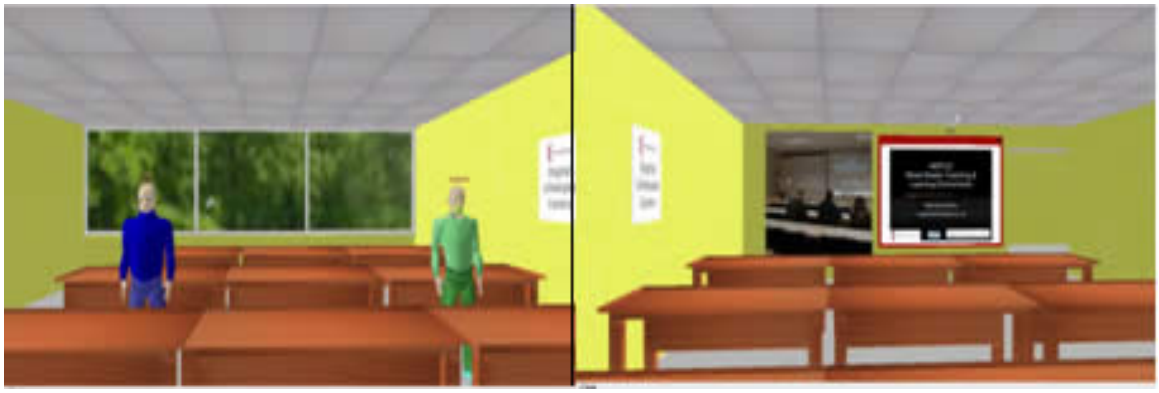


Figure 2.5: Lecturer's View of Remote Students (left) and Remote Students' View of the Lecture (right) [6]

A similar approach that primarily uses the concept of MR is the Holodeck environment [7]. This application is based on Open Simulator, which is an multi-platform, multi-user open source 3D application server for hosting virtual worlds written in C#. The Holodeck

essentially extends the MiRTLE project. It attempts to bring the real environment and the virtual environment into what is called a 'mash-up' that is to combine a real classroom where students meet in-person with a virtual classroom where students meet as avatars, so that all students can in both real and virtual classrooms in ways that may be more natural feeling and promote social interaction.. The difference between the Holodeck and MiRTLE is that, in the Holodeck, the physical students experience the virtual using their iPads within real classrooms. Then, they engage in interactions and communications with one another, as shown in figure 2.6 on page 14.

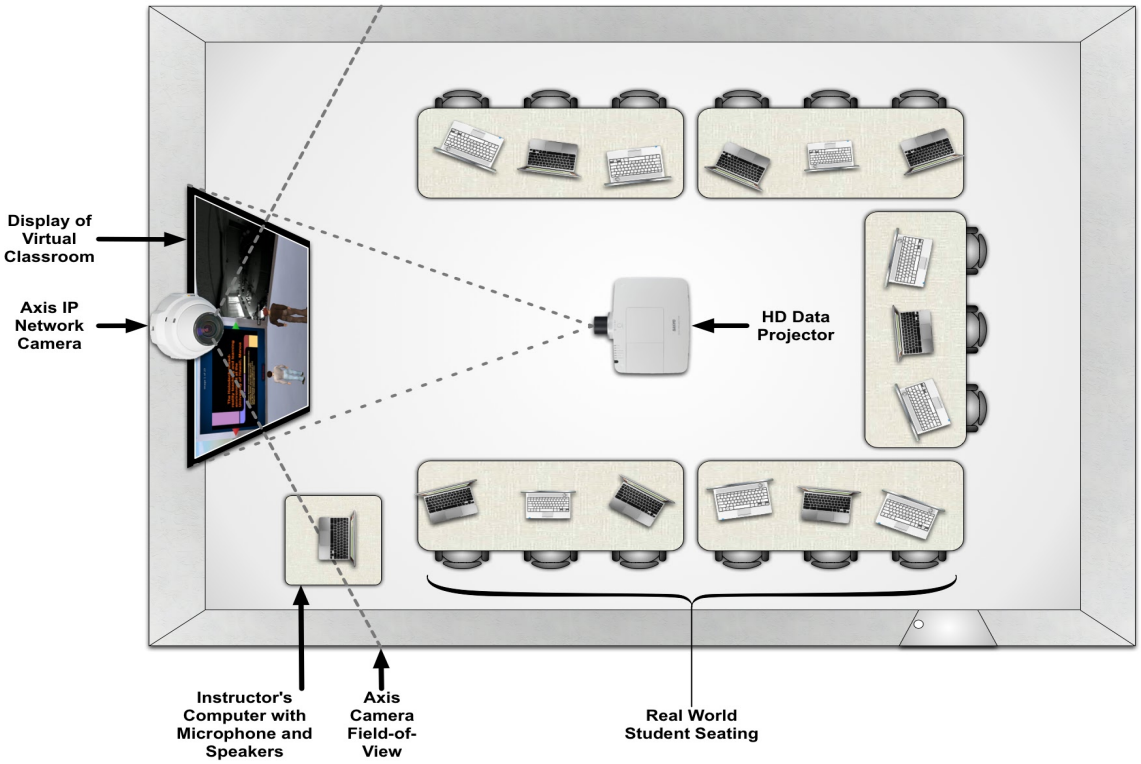


Figure 2.6: Mixed-reality Holodeck environment [7]

The above figure shows the real classroom where students use their own machines to login to the virtual 3D environment. From within the virtual classroom they can communicate, and interact with each other as shown in the mounted screen displayed by a projector.

Moreover, the remote students' avatars can be viewed on the screen based on the users' preferences [20, 18]. Therefore, the virtual students' existence in the real world is screen-based,

which can be seen as a limitation in terms of facilitating more interactive communication in physical classrooms with real students.

2.1.1 Augmented Reality (AR)

The term Augmented Reality (AR) was first defined by Caudell and Mizell [22]. AR refers to a real-world (physical) environment whose elements are augmented by computer-generated sensory inputs, such as sound, video, graphics or GPS data. It relates to a more general concept called mediated reality, in which a view of reality is modified by a computer [23]. AR systems comprise three key points [24]:

- Binding real and virtual objects in a real environment.
- Registering real and virtual objects with each other.
- Making the use of 3D and 2D objects in a real environment.

Recently, engineers at Microsoft developed a fully immersive augmented reality technology called HoloLens [25]. HoloLens is an advanced computer headset that enables the projection of images on top of the real world. This approach differs from that of the Oculus Rift, which projects an immersive virtual environment that surrounds the user [26].

In addition, another study uses the Second Life[1] world and the MR concept to support collaborative teleconference to enable hand tracking, gesture and object interactions by augmenting reality [27]. However, the limitations are obvious: users are restricted to head-mounted glasses, rather than handy smart pads or phones.

In educational spaces, using AR configurations is an obvious alternative for promoting engagement and motivation among educators in classrooms. For instance, an AR-based game called Learning Words, which uses a head-mounted display (HMD) device, was developed and tested with 32 pupils. The results indicate that more than 80% of the users preferred AR sys-

[1] http://secondlife.com/

tems to conventional systems for learning [28]. Books are a primary tool with which learners are already familiar in education (e.g. flipping pages and searching among pages) [29]. Thus, researchers have used the book metaphor in content-based AR systems to develop 3D virtual content, for example based on a real book such as with the 'MagicBook' [30, 31, 32, 33]. An example of an AR commercial tool that supports the magic book metaphor is Zooburst [34]. Sin and Zaman [35] conducted a between-subjects study in a high school to measure the learning effectiveness (one of their factors) in a solar system topic using the Magic-Book metaphor. Their findings show that the AR-based group's learning increased by 29% compared to conventional book learning.

2.1.2 Augmented Virtuality (AV)

A virtual environment embedded with real objects is part of Milgram's Reality-Virtuality continuum, which is referred to as Augmented Virtuality (AV). AV is the opposite of augmented reality, since the primary environment is virtual and real objects are only attached to it. AV can be used as a means to combine a richly layered, multi-modal real 3D experience into a virtual environment (VE) [17]. However, this advanced technology has not received as much research attention as AR [36]. AVs are limited to a few domains, such as 3D video-conferencing systems [36, 37].

2.1.3 Virtual Reality (VR)

A virtual reality (VR) world (also called a virtual world, a synthetic world, a three-dimensional [3D] environment or a virtual environment) is a computer-generated environment that visually simulates a complex real environment where users can interact with one another and with virtual objects and where users can be represented by characters (avatars) [38]. A large number of studies have explored the use of VR applications for pure educational purposes ([39, 40, 41], among others). A good summary of educational VR applications is given by

Mantovani Mantovani [42]. VR (i.e. 3D virtual world based on PC screen) provides opportunities for students and teachers to communicate and interact in a dynamic environment through standard personal computers (PCs), such as those that commonly exist in schools and homes; therefore, VR systems have been successfully integrated into university courses as platforms for experimental learning [43] and role-play [44].

VR environments can be distinguished from more traditional 2D learning environments (e.g. Blackboard[1], eFront[2]) by their characteristics of three dimensionality, interactivity and the support they provide for flexible physical changes [45]. The use of an illusory space enables users to communicate with one another and to interact with the 3D objects that populate it [38].

From a learning theory point of view, 3D environments can help students achieve learning outcomes through constructivist and problem-based learning [46, 18]. Furthermore, the use of 3D virtual environments in teaching and learning has the following advantages [47, 48, 49]:

- learners can take part in learning activities from anywhere. This enables students to engage in distance learning from their homes;
- learners can walk, fly and teleport inside virtual worlds without any physical constraints. This can help learners shift between various learning activities and engage in more activities;
- 3D virtual worlds help teachers and students meet and interact more easily. Moreover, different groups of people around the world can meet through educational activities, fostering the opportunity for greater cultural exchange;
- compared to other online facilities, such as emails and forums, 3D virtual environments facilitate more interactive communication through avatar movements and gestures.
- 3D virtual worlds simulate the real world; thus, students can engage in dangerous or

[1]http://uki.blackboard.com/
[2]https://www.efrontlearning.com

difficult activities without the risk of actual harm. For example, medical students can carry out simulated surgery operations;

- the nature of the 3D virtual environment (e.g. a game) can have a positive effect on the students' engagement in the learning activities.

However, as the VR has been identified as a desirable technology in such sectors as education, health and military [50], several studies [51, 52] have advanced more complex perspectives, positioning VR as a psychological human experience and stating how "the essence of VR is the inclusive relationship between the participant and the virtual environment" [53]. In this context, various concepts, such as presence, immersion and engagement are crucial [54, 55, 56]. These concepts are discussed in different sections later in this chapter.

2.1.4 Integrating virtual and augmented realities

There are several applications (e.g. games) that use the augmented reality of a first-person perspective view to interact within the virtual environment from the real world. Thomas et al. [57] proposed an application game to endow players in an outdoor real environment the freedom to interact with hybrid environments. In late 2001, in Sheffield, UK, another chase game called Can You See Me Now (CYSMN) was implemented to engage online players using the screen with physical runners in the city. Both types of players shared an online map to help them find one another within the game: Online players could see a virtual red avatar on the shared map; and the runners could see their points on a handheld device linked to a GPS service [58].

Another study [59] focused on exploring the connection between outdoor AR systems and VR systems to generate a battle environment for low-cost and safe training and observation. The system supported the collaboration between AR and VR systems, and the virtual environment contained vehicles and troops in a battle environment, where the user (soldier) could interact and move about using a wearable computer Tinmith, which makes augmented

reality applications achievable outdoors. The soldiers follow enhanced instructions and deal with the situations presented in the environment. They can also be monitored and see one another using the e1upped GPS and digital compass devices, which reflect their movements in the virtual environment. Another study [60] explored the use of wearable computers, such as Tinmith, pinch gloves and hand tracking, to achieve virtual tasks. This study's basic contribution was to build 3D graphical objects from a large, real-world building using the hand tracking and HMD on the users' Tinmith computers.

Though the above-mentioned studies have focused on the importance of interconnecting AR and VR in terms of the user benefiting from the virtual environment, there are some drawbacks of using these technologies. Firstly, they lack of simultaneously bringing the avatars presence in the real environment by using low-cost handheld devices. Secondly, the shortage also appears in how much these technologies are able to increase users presence and engagement during their collaboration from distant places. Therefore, there remains a gap in the literature related to the impact of these technologies for various collaborative learning scenarios from a psychological perspective.

2.1.5 AR and VR displays

There are several ways that AR can be used to display 2D or 3D objects in the real world, including screen-based interfaces, handheld interfaces, see-through interfaces and projection interfaces [17, 24]. A see-through interface must be mounted on a user's head (creating a so-called HMD or head-worn display). This technical concept depicts objects in two ways: the optical see-through method, which provides an AR overlay through a transparent display; and the video see-through method, which provides a video that captures AR objects and images within the real world and displays them to users as video-generated images [24].

As a type of MR environment, AR includes some features of VR that can facilitate teaching and learning. For example, Chen [61] noted that AR technologies can (1) draw attention;

(2) create interactive learning spaces; (3) provide a sense of presence; (4) simplify conceptual learning; (5) retain the user's view of the world and body motions; (6) offer opportunities for bodily learning; and (7) provide a means to require users to think carefully.

The relative benefits of handheld and wearable AR devices have long been debated. When they developed their collaborative AR tablet-based system, Wagner et al. [62] stated that wearable technologies are relatively expensive, heavy, fragile and unsuitable for large-scale platforms involving untrained people outside a constrained laboratory. Handheld devices, such as mobile phones and tablets, are still overcoming these drawbacks. On the other hand, some wearable devices, such as Google glasses, are considered to be superb examples of AR use [63]. They provide more immersive and intuitive settings by abandoning the need for the user to hold a device in front of him/herself [64]. Furthermore, according to Chang et al. [65], wearable glasses designed to look like normal spectacles and equipped with lightweight mini-computers and sensors are expected to be the next evolution beyond smart handheld devices. For the present study, Meta 1 glasses, which are wearable HMDs that incorporate many of the functions one would find in a smart tablet, were used for the AR implementation. Compared to other wearable devices, most of which are still in development, and support only 2D views or are not (or scarcely) commercially available, the Meta 1 3D AR glasses offer the most support, reliability and affordability at the time of writing this thesis. They also incorporate a significant number of components into a relatively small, lightweight and highly-functional device (though they do still have certain software and hardware constraints related to deployment and development factors).

VR spaces can be viewed through normal PC screens, as well as more specialised hardware such as ImmersiveDesk Displays and the Cave Automatic Virtual Environments (CAVE), as well as the above–mentioned tablet and glasses devices. These 3D spaces represent a new paradigm of human-machine interaction involving using the mouse, the keyboard or even the touch screen. Immersion within these spaces depends on two primary components: the depth of information (e.g. resolution, quality and effectiveness of visuals and audio) and the

breadth of information (i.e. the amount of sensory experiences presenting at a single time) [66]. Through its glasses interface, Oculus Rift is a VR HMD device that works alongside computers or mobile devices, and is very lightweight. The use of HMD can enable users to better engage with a VR game and provide more flexible degrees of movement (e.g. the ability to look around in any direction [26]). Though Oculus Rift operates under constrained software and hardware requirements, these requirements are still few compared to those of the new Meta 1 AR glasses.

The CAVE is "a system where between four and six walls of an approximately $3 \times 3m$ room are back-projected stereo projection screens. The images are determined as a function of head tracking so that, at least with respect to the visual system, participants can physically move through a limited space and orient their head arbitrarily to be able to perceive (but not necessarily from all directions depending on how many screens there are). Audio is typically delivered by a set of speakers in unobtrusive positions around the Cave" [67, 68]. The CAVE is a 3D interface that enables the integration of the concept of MR.

Another interface that provides an immersive view of VR is Immersive Display's ImmersaVu[1] 10. This is 'a composite moulded panoramic dome screen, which allows a free–range of head movement without the need of any special instrumentation such as glasses or other devices that can interfere with the learning session' [69].

In education, Lee et al. [70] found that using the features of a 3D virtual environment in a secondary school lesson positively affected the students' sense of presence, which, in turn, improved learning effectiveness. On the other hand, Merchant et al. [71], who conducted a study on an undergraduate chemistry course, found no key link between presence and learning effectiveness, though they did find that 3D virtual environment features indirectly influenced physical presence. Moreover, Moreno and Mayer [72] found that using HMDs increased the students' sense of presence in immersive virtual environments; however, they found no increase in learning effectiveness. In short, a number of studies have investigated the

[1] www.immersivedisplay.co.uk

benefits of various types of mixed and augmented realities, including fostering user experience [73, 74], improving learning performance [75, 76, 77], enhancing collaborative working in a virtual environment [78, 79, 80], increasing levels of presence [81, 82], enhancing levels of immersion and engagement [83, 56, 84, 85] and exploring the features and psychological factors of AR smart glasses [86, 87]. Little attention has been paid to how the use of different user interface with groups of learners in collaborative mixed and augmented reality spaces can impact on the learning effectiveness, and user's sense of presence, immersion and engagement.

2.2 Telepresence

Telepresence refers to set of technologies, such as high definition audio, video, and other interactive elements, that enable people to feel or appear as if they are present in a place when they are not. Telepresence is mainly used as a collaboration tool by companies to help create more 'in person' meeting experiences over converged networks [88]. According to Bengler and Passaro [89], AR can be classified as a technique distinct from telepresence and virtual environments, as shown in figure 2.7 on page 23.

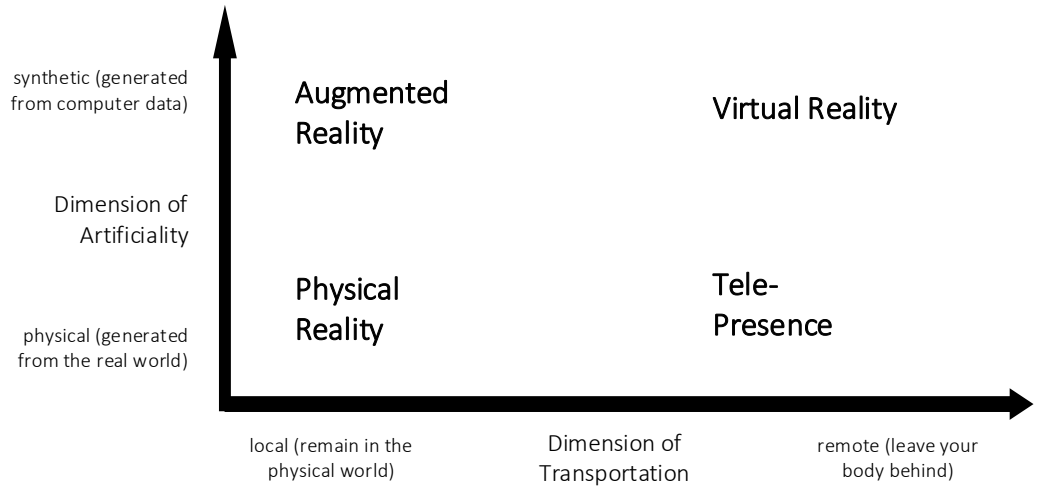


Figure 2.7: Broad classification of shared spaces according to transportation and artificiality [89]

The above figure shows the classification of AR, VR and Tele-presence concepts based on the dimension of transportation and the dimension of artificiality.

In addition, telepresence can be described as a condition of presence within a targeted remote environment. From a virtual environment perspective, telepresence can be achieved by controlling an avatar's motion through so-called 'first person games', through which a user sees an environment through the eyes of their avatar [4]. This sort of telepresence uses different user interface approaches to enhance the user's immersion into the virtual environment and their avatar interactions. However, researchers are also interested in the reverse problem, that is, bringing avatars into a real environment to communicate with real people and benefit from the real environment devices.

In terms of controlling remote robots, the tele–existence concept was first proposed in 1980 for the Advanced Robot Technology in Hazardous Environments project. This technology allows us to both manage distant objects and communicate with others in distant environments. Moreover, tele–existence creates a real–time feeling of 'being there' using agent robots and distant or local computers [90]. Tele–existence systems are master-slave relationships, in

which all control is held by the master in a distant environment. They also use mechanical or magnetic sensor systems to facilitate tele-processing [90]. Another study [91] proposed a visual system called tele-AR to overcome the problems of inconsistency between master and slave devices when using tele–existence systems (e.g., with the slave being commanded through the fast movement of a user's head via an augmented visual system for remote objects with the actual slave cameras).

Social interaction

The social interaction of users' presence refers to "the degree to which media are capable of making users perceive other users' sociability, warmth, sensitivity, personality, or closeness in a mediated communication situation" [92]. A high level of social interaction of users' presence means that users have a sense of being in and belonging to, as well as the ability to interact with other students and instructors, even though physical contact is not possible [92].

In relation to the learning perspective, the social cognitive theory explains that students' learning is based on acquiring knowledge by monitoring others through interactive communications and experiences [93]. Remote and local students may have a greater feeling of 'being there' if they can physically see one another during the learning process.

Another paradigm that is a type of collaborative learning is computer–supported collaborative learning (CSCL), in which technological devices and systems are used in an environment to assist in mediation and underpin the educational group interactions. Such CSCL technologies can also be utilised to observe and manage interaction tasks, rules and roles [94].

One factor that plays a key role in interactions is the communication medium being used. Face–to–face interaction, for example, supports far stronger results in cases requiring rapid information feedback [95]. Olson and Olson[96] stated that this illustrates the importance of face–to–face interactions, regardless of whether two communicating individuals are geographically proximate or not. A serious weakness of this argument, however, is that most

education–related MR environments seek to enhance students' presence in relation to their fellows and teachers to avoid loneliness in learning and that more interactive communications tend to occur if the remote virtual avatar (i.e. the student) can see and talk to the local teacher, as in the MiRTLE system [6].

Therefore, this thesis studies the psychological aspects, such as interaction, involvement and collaboration, that manipulate key roles in the learning and teaching effectiveness of these VR, AR and MR environments under the umbrella of human–computer interaction. We specifically consider three important overarching factors: presence, immersion and engagement. These will be discussed further in the next section.

2.3 Human-Computer Interaction (HCI)

The term Human–Computer Interaction (HCI) term first gained popularity at the beginning of 1980s; however, it was found primarily in different disciplines, since technologies mediate many activities in which we engage in our daily lives. Because of the widespread use of computers, researchers have studied the interactions between humans and computers from different points of view: physical; psychological; and theoretical. These interactions were first called man–machine interactions; however, this term was superseded by human-computer interaction following increasing interest in computers and the changing composition of the user population [97].

Implementing educational software requires extensive exploration of pedagogical, technological and psychological aspects [98]. This study investigates users' interactions with various technological interfaces in a collaborative AR and MR space. Furthermore, it considers primarily the psychological concepts of the senses of presence, immersion and engagement for users at different levels of expertise from the perspectives of learning and teaching.

2.3.1 Communications and collaborations model

Effective communications clearly inspire much collaborative work, and many systems exist that aim to support communication at a distance. Face-to-face communication is often seen as the ideal to which computer mediated communicating should aspire. Considering face-to-face communications means enabling not only speech- and hearing-based communication, but also body language and eye gaze communication [97]. Several factors affect face-to-face communication. For example, Economou [99] studied the role of human representation in CVE to support communication, turn talking and collaboration. One of these is personal space, which is the space between two participants. Another is eye contact and gaze. For example, a person can often tell from his/her communication partner's eye gaze whether the partner is listening to him/her or not during a conversation. Gestures and body language represent the third method two people can use to clearly understand one another. For example, a person saying "let's move this table there" could move his/her hand (gesturing) or eye gaze to point to the target location [97].

A group working model is an important aspect of effective communications. Communication in groups is more complicated than communication between two people, since it must consider the dynamic social relationships among group members. Several factors influence the success of group communication. The first of these is group dynamics. Group members, structures, roles and subjects may change dynamically over time; therefore, when developing a group communication system, we must consider these elements [97].

2.3.2 Task analysis model

In HCI, task analysis can help to guide the design of new (though possibly not novel) systems. Task analysis is considered a further stage of system requirements, designed to identify all included system components as either part of the system or not. It seeks to strengthen the definitions of customer requirements to help a developer think how the system will be used,

in addition to what it should do [97]. Objects and actions must be classified in terms of their functionality in the system, which can be done through the use of clear tasks statements. Put differently, user task analysis is the basis for designing what a user needs to achieve on the system. This analysis assists in the creation of a list of detailed task descriptions, relationships, sequences and user work. Thus, it is beneficial for evaluators to participate in user task analysis [100, 101]. Furthermore, task analysis is also used to evaluate the system bing applied in education as this will be discussed later in this chapter.

2.3.3 Presence

Most researchers interested in the concept of presence have attempted to understand the essence of presence: the factors that manipulate it and the methods to measure it [102]. Presence can be defined as one's existence, occurrence or presence within an environment [23]. This definition does not necessarily require a real physical person; however, it does require the person's perceptual experience, mental representation and sense [103]. Presence can also be defined as "the sense of being in an environment" [23].

Heeter [104] distinguishes three different types of presence. First, personal presence refers to one's ability to inhabit a VR remote from the real world [105, 106], giving the perception of the self being at a certain location. Several VRs provide avatars to generate a strong sense of personal presence [104], since the distinction between self and non-self occurs at the boundary of the body [107]. Secondly, social presence is one's sense of interacting with others, which can provide evidence of a user's existence, thus increasing their sense of presence and influencing the user's attitudes [108, 104]. Finally, environmental presence refers to the reaction of the environment to the user, which can also provide evidence of a user's existence. A user's ability to modify the environment is an important factor in achieving environmental presence [108]. According to Lombard and Ditton [109], the concept of presence is characterised by six features: social richness, realism, transportation, immersion, as a social actor within a medium and a medium as a social actor. The most popular features of the concept of

presence proposed by researchers are realism and transportation. Realism shows the range to which a VR appears to be realistic, and transportation represents people's cognitions of being present in the VR. These features of presence are related to people's perceptions or 'mental state' [102].

From another perspective, Witmer and Singer [110] stated that two concepts must be considered in order to measure presence in VRs: involvement and immersion. Involvement is "a psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities and events" [110]. To some extent, we may say that users become more involved as their attention becomes more related to the stimuli of a VE. Immersion, on the other hand, is a "psychological state characterised by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" [110].

Considering presence as a mental state, questionnaires are considered to be a viable method of evaluating presence through participants' feedback [111, 112]. Researchers have developed a number of subjective questionnaires based on theories concerning several key aspects of presence [105]. The questionnaires that are most commonly used to evaluate presence are: Slater and colleagues' questionnaires; the Presence Questionnaire (PQ); and the Immersive Tendencies Questionnaire (ITQ) and the Igroup Presence Questionnaire (IPQ) [113, 110, 114]. Many researchers have also formed their own customised questionnaires. Slater and colleague's questionnaires are based on three indicators of presence: the subjective sense of 'being there' within a virtual world; the extent to which the VE becomes more 'real' than everyday reality; and the sense of having visited a place rather than having just seen images of a place. By contrast, the IPQ questionnaire was developed based on previously mentioned questionnaires. Schubert et al. [114] considered basing the IPQ on eight factors: three for presence (Spatial Presence [SP], Involvement [INV] and Realness [REAL]); and five for immersion (Quality of Immersion [QI], Drama [DRAMA], Interface Awareness [IA], Exploration of VE [EXPL], and Predictability [PRED]). Finally, the PQ was developed based

on several factors that contribute to measuring presence in VE based on immersion, user involvement or both. These are Control (the amount of control the user has over events in the VE), Sensory (the quality, number and consistency of displays), Realism (the degree of realism of the portrayed VE) and Distraction (the degree of distraction by objects and events in the real world), as detailed in table 2.8 on page 29. These factors assist in the formation of the subjective PQ questionnaire. This study uses the PQ to measure presence for several reasons: the PQ was developed based on comprehensive factors, its factors are compatible with our platform components and it has been extensively tested and validated by many researchers. Furthermore, the reliability and validity of the PQ have been statistically proven through a number of studies [110, 102, 12].

Control Factors	Sensory Factors	Distraction Factors	Realism Factors
Degree of control	Sensory modality	Isolation	Scene realism
Immediacy of control	Environmental richness	Selective attention	Information consistent with objective world
Anticipation of events	Multimodal presentation	Interface awareness	Meaningfulness of experience
Mode of control	Consistency of multimodal information		Separation anxiety / disorientation
Physical environment modifiability	Degree of movement perception Active search		

Figure 2.8: Factors hypothesised to contribute to a sense of presence [110]

Daher et al. [82] and Proffitt et al. [81], who focused on users' collaborations with game-based learning tasks, reported that statistically significantly larger presence level means was found for participants in virtual world experiences than for participants in real world experience. However, a reality test study conducted by Usoh et al. [113], who recruited users for a search task within simulated virtual and real offices and tested their sense of presence using the PQ, showed no significant difference by using the (PQ). Another study by Chen et al. [12] explored the differences in presence between AR displays (i.e. webcam and HMD) for learning basic concepts about protein structures and how these differences affected learning

tasks. The presence results showed no significant differences between displays. As a result, they suggested to use low-cost webcam for the future use of AR inside the classroom.

2.3.4 Immersion

The concept of immersion has been investigated primarily in the context of games and virtual environments [55, 115, 83]. Immersion is defined as a user's sense of absorption within the world of the game [116]. From a gamer's point of view, immersion is one's degree of involvement in technology. This degree of involvement considers various human, computer and contextual factors (e.g. environment construction, player preferences and game construction) [117]. Within virtual environments, Witmer and Singer [110] also define immersion, as mentioned previously, as a "psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" [110].

Researchers have conducted qualitative and quantitative studies to identify the factors that affect degrees of immersion. Brown and Cairns [117] suggested that immersion can occur at three levels: engagement; engrossment; and total immersion. A player moves between these levels when s/he moves from one state to another (e.g. from investing time and effort into learning how to play a game to feeling less aware of his/her surroundings to the state where they "stop thinking about the fact that you're playing a computer game and you're just in a computer") [117]. Witmer and Singer [110] further proposed that immersion can be affected by isolation from the physical space, perceptions of self-inclusion in the VR, natural modes of interaction and control and perceptions of self-movement. Jennett et al. [83], however, described these factors as descriptive rather than predictive. They concluded that immersion has the following characteristics:

- Lack of awareness of time.
- Loss of awareness of the real world.

- Involvement and a sense of being in the task environment.

Jennett et al. [83] built a subjective measurable questionnaire called the Immersion Experience Questionnaire (IEQ) considering the factors identified in previous studies [118, 117]. They consider the process of measuring immersion to be the relationship between a user and a video-gamethrough by applying the main factors of control, challenge, real world dissociation, emotional involvement and cognitive involvement. Their objective evaluation also considers issues related to real world disassociation and eye movements. Their IEQ has been tested and validated within AR systems in various studies (e.g. Lee Corbin [84], Jennett et al. [83]). Finally, another study [119] explained immersion as user interruptions over a period of time. Their questionnaire to measure immersion included only one question: *'How much would an interruption of 10 minutes of the game have disturbed you?'* Most of the above-mentioned psychological measurements are used primarily for computer games. However, these measurements can also be used for learning purposes within MR (and, thus, AR) environments. Lee Corbin [84] noted the similarity between AR systems and games by stating that both display graphical content and illustrate information in a story-like form to increase the users' involvement in a given context. Moreover, the IEQ is a subjective measurement that asks users about their feelings of immersion after a task; thus, it depends on user self-evaluation. Therefore, based on the similarities between AR systems and games, as well as on the objectives of the IEQ questionnaire for gamers, we propose using the IEQ in our study to measure immersion, since learning is a game-based activity within a collaborative MR learning space.

2.3.5 Engagement

When a student's attention is focused on reading a book, playing a computer game or engaging in a conversation, and they are excluding other stimuli, then the student can be said to be completely engaged. Engagement can be described as

"being concerned with all the qualities of an experience that really pull people in whether

this is a sense of immersion that one feels when reading a good book, or a challenge one feels when playing a good game, or the fascinating unfolding of a radio drama" [120].

Engagement is most often related to personal involvement and immersion [121]. As presented in the previous discussion, the concept of engagement is related to the concepts of immersion and presence. Brown and Cairns [117] theory of immersion defines engagement as a user's first stage of becoming familiar with a game environment. By contrast, Chen et al. [122] described engagement as occurring after the stages of fidelity and immersion. To be more precise, students feel engaged with world objects after they had a degree of belief in the exactness of these world objects produced by computing systems and without other distractions. From a collaborative learning point of view, engagement involves students' attention or reflective participation in a group [123]. Moreover, Ross [124] defines the relationship between learning and engagement as reflecting a student's efforts to engage in both learning activities and other non-academic campus activities. Researchers have proposed that engagement can be enhanced or impeded by technologies [123, 124] and various psychological factors. Kuh et al. [125] identified five aspects of engagement, which are: active and collaborative learning; studentfaculty interactions; a supportive campus environment; enriching educational experiences; and different levels of academic challenges. Furthermore, in the context of education, various conditions and circumstances affect students' engagement, including classes, cultures, expectations of behaviours, relationships among learners or between learners and instructors, individual motivations and factors outside the learning system, such as family responsibilities [126]. Flow theory, proposed by Csikszentmihalyi and Csikszentmihalyi [127], is a commonly used theory among game researchers (e.g. [128, 129]). Flow is described as "the state in which people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it" [127]. Thus, flow theory assists games researchers in understanding the exciting nature of digital games. For example, Hamari et al. [85] undertook an empirical study in game-based learning and defined engagement as "the simultaneous occurrence of elevated concentration, interest, and enjoyment encapsulating the experience

of flow" [85]. Another study considered the qualitative factors of challenge, curiosity, fantasy and flow as critical for engaging with a game [130]. Douglas and Hargadon [131] stated that flow is involved in both immersion and engagement. The following figure 2.9 on page 33 shows a simplified diagram of various (mentioned-above) theories linked to engagement.

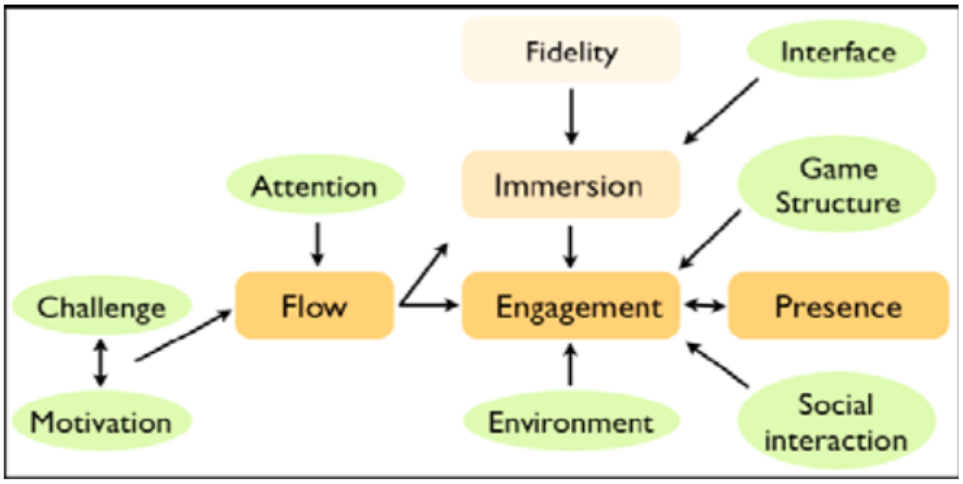


Figure 2.9: Engagement model summarising the various theories [132, 133]

Several questionnaires have been developed to measure engagement. These include the Game Engagement Questionnaires (GEQ) [56, 134] and the Game Experience Questionnaire [134]. Brockmyer et al. [56] built their questionnaire to measure engagement in computer games using variables related to engagement (i.e. flow, cognitive absorption, dissociation and presence). The GEQ has been tested and validated, and the results display high reliability (using Cronbach's alpha) [56]. The GEQ was originally constructed for game-based environments; therefore, given the similarity between MR spaces and computer games with respect to the immersion variable (described earlier), the GEQ can be adapted and applied to this study.

McMahan et al. [135] conducted a within-subject study to measure the differences in user engagement using a modified GEQ (among other factors) in two conditions: a low-fidelity traditional first-person shooter (FBS) game and a high-fidelity FBS game mimicking the real world within a six-sided CAVE. In this study the participants were significantly engaged within the high-fidelity game. Another study conducted by Schild et al. [136] used GEQ factors to compare two vision conditions (stereoscopic and monoscopic) in computer game

play and found significant differences between participants using the two conditions; however, the immersion level represented the only statistically significant difference.

2.3.6 Usability

The efficacy of a developed system must be measured by end users to determine how well the system meets user requirements based on such factors as ease of use, efficiency and attractiveness. Popular tools for measuring user experience are based on subjective questionnaires [137, 138]. One commonly used questionnaire for measuring user experience is the User Experience Questionnaire (UEQ). The UEQ contains six scales: attractiveness; efficiency; perspicuity; dependability; stimulation; and novelty, as depicted in figure 2.10 on page 35.

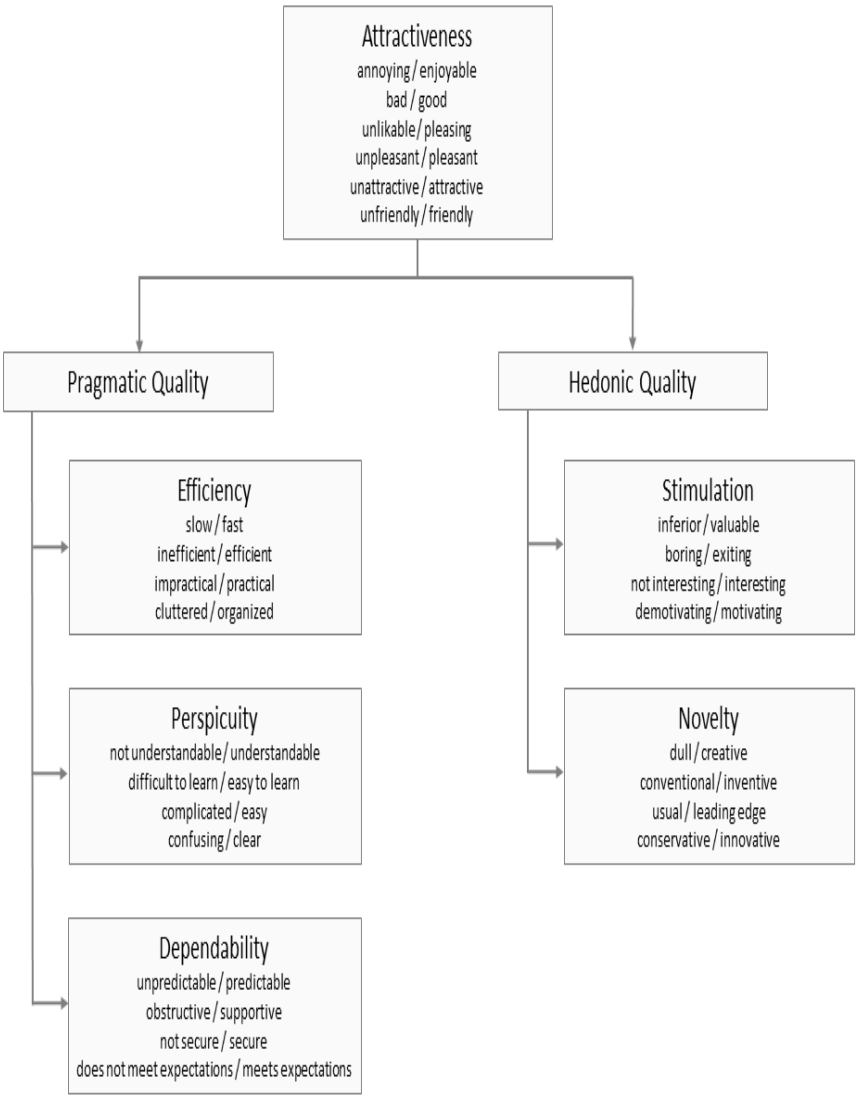


Figure 2.10: Assumed scale structure of the UEQ [138]

Laugwitz et al. [138] defined each scale of the UEQ as follows:

- Attractiveness: Overall impression of the product. Do users like or dislike the product?
- Perspicuity: Is it easy to get familiar with the product? Is it easy to learn how to use the product?
- Efficiency: Can users solve their tasks without unnecessary effort?
- Dependability: Do users feel in control of the interaction?

- Stimulation: Is it exciting and motivating to use the product?
- Novelty: Is the product innovative and creative? Does the product catch the interest of users?

One of the advantages of the UEQ is that it offers an Excel tool for analysing and comparing platforms with 163 software evaluations (for a total of 4818 participants across all evaluations). Moreover, the quality of the UEQ has been tested and validated in various case studies [138].

2.4 Learning

2.4.1 E-learning

E-learning is the provision of technologies to help people learn anytime and anywhere. According to Schmidt et al. [7], technologies play an indispensable role in improving learning outcomes. Previous studies in this chapter have illustrated some of these improvements. However, we must also consider the disadvantages of using technologies and their potential negative effects on learning outcomes. The following table 2.1 on page 37 illustrates the key differences between a traditional classroom and e-learning in terms of their advantages and disadvantages.

Table 2.1: Traditional classroom learning vs. e-learning [139]

	Traditional classroom learning	**E-learning**
Advantages	• Immediate feedback • Being familiar to both instructors and students • Motivating students • Cultivating of a social community	• Learner-centred and self-paced • Time and location flexibility • Cost-effective for learners • Potentially available to global audience • Unlimited access to knowledge • Archival capability for knowledge reuse and sharing
Disadvantages	• Instructor-centred • Time and location constraints • More expensive to deliver	• Lack of immediate feedback in asynchronous e-learning • Increased preparation time for the instructor • Not comfortable for some people • Potentially greater frustration, anxiety, and confusion

2.4.2 Learning design and effectiveness

A learning design is described here as the application of learning design knowledge to develop a unit of learning, such as a course, a lesson, a curriculum or a learning event. The learning design specification also offers new pathways for educational researchers and developers, since the various approaches to learning and teaching are easier to compare when they are described and delivered in a formal language defined in an open, technical specification [140].

Levels of learning outcomes are related to effectiveness, efficiency, attractiveness and accessibility. Effectiveness refers to how successfully learning objectives are met by learning design methods. For example, when 85% of students successfully complete an exercise, the learning method can be considered to be effective. By contrast, if only 30% of students pass the

final assessment, then the learning method is less effective. Efficiency describes the work intensity and the cost of the learning method for both students and teachers. Attractiveness refers to whether the learning activities are attractive to learners and teachers. Lastly, accessibility describes whether the learning facilities are easily accessible to both teachers and students; whether there are time constraints related to learning and whether the facilities can be adapted based on students' circumstances [140].

A learning designer's basic task is to design a course that meets a set of learning objectives. The learning designer may be a course developer, a curriculum developer, a teacher, a trainer, a coach, a mentor or a learner who designs his or her own learning plans [140].

Considering a broad definition of learning outcomes within virtual environments, researchers and instructors frequently question whether these virtual spaces truly foster increased learning performance. Dillenbourg et al. [141] stated that virtual environments have the potential to influence education but that this potential rarely manifests as actual effects. This finding was also supported by [142], which illustrated that a computer-based learning environment offered small benefits related to, for example, the time of learning and the locations of learners. However, the technologies did not outperform traditional learning effectiveness. On the other hand, mediated technologies can enhance learning effectiveness. These effects are most obvious when these technologies are used as assistive tools in teaching and learning processes [141]. Dalgarno and Lee [45] explained particular features of virtual environments and evaluated the benefits of virtual learning environments from an ecological psychological view and noted that perceived information occurs in virtual environments and that virtual learning environments supported learners in learning. In their learning model (as shown in Figure 2.11 on page 39), the features of virtual environments (e.g. representational fidelity and learner interaction) can encourage the users to construct an online identity and lead to an increased senses of presence and co-presence, which, in turn, can produce enhanced learning benefits, using techniques which promote spatial knowledge representation, engagement, experimental learning, contextual learning and collaborative learning, via afforded learning

tasks.

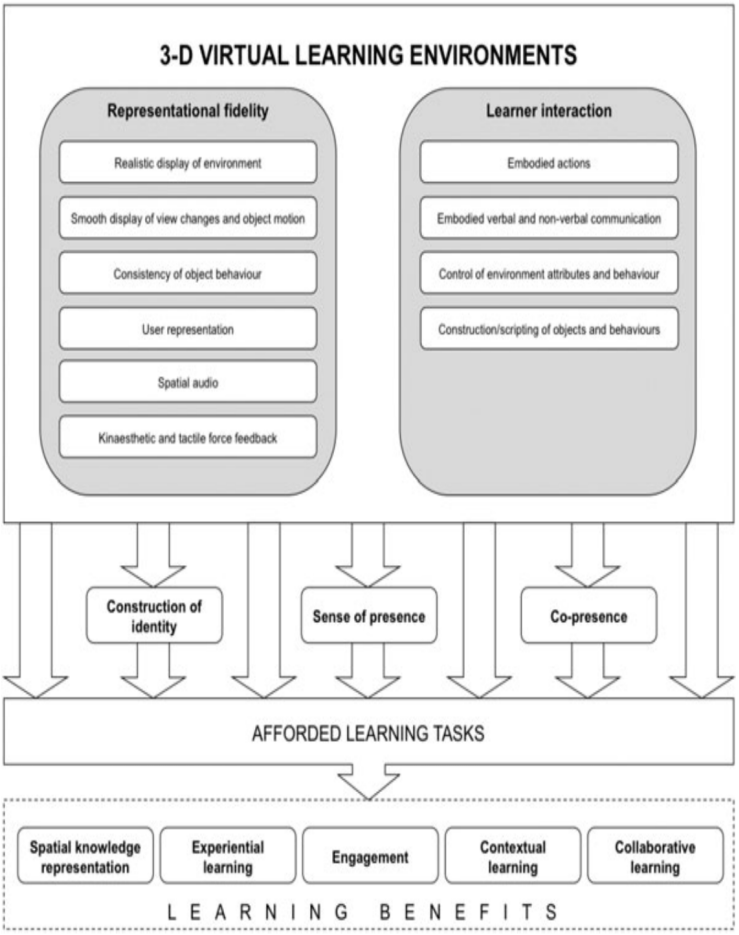


Figure 2.11: Elaborated model of learning in 3-D VLEs [45]

Therefore, virtual environments can be considered to provide effective environments when created with these distinctive characteristics and affordances, rather than simply tools for learning. In relation to the pedagogical view, various studies have assessed these technologies and found that virtual environments are considered to be suitable environments for reflecting changes in students, technologies and learning paradigms [143, 144, 145, 146].

2.4.3 Teaching experience

According to Bebell et al. [147], although the use of technologies is increasing in the field of education, many would argue that it has not prompted significant changes to student

achievement or instructional practices.

Effective education through technology use supports (with good teachers) with cutting-edge tools to enhance and improve learning effectiveness through communicating, demonstrating, explaining, involving and engaging students [148]. Moreover, 'Teachers need to know not just the subject matter they teach but also the manner in which the subject matter can be changed by the application of technology' [149]. From a pedagogical point of view, teachers need to evaluate which available technologies can best support them in enhancing learners' achievements and, thus, whether they aid or hinder the teaching and learning process [150]. To address this issue, a number of factors and frameworks have been investigated to measure teaching experiences with technology [151, 149, 152, 153, 154]. For example, Vannatta and Banister [155] conducted a study to investigate the integration of technology into the classroom from the teacher's perspective. Their study considered technology-related and non-technology-related factors. However, for the purposes of this study, only two of the technology-related factors have been used. These are: (1) Risk-taking Behaviours and Comfort with Technology; and (2) Perceived Benefits of Using Technology in the Classroom. The sub-scales of the first factor measures the emotional responses of comfort and anxiety, whereas those of the second factor measures perceptions of the emotional and academic benefits of using technology among both teachers and students [155]. The present study adapts and applies 11 items from both factors using 4-point Likert scales. These 11 items are presented under the *Teaching Experience (experts)* section in appendix .1 on page 185.

2.4.4 Distance learners in VR

Due to work, family and other commitments, students may choose to study using distance learning tools. However, most learners also prefer regular face-to-face education [156]. As we discussed earlier (sub-section 2.3.1 on page 26), face-to-face learning supporting collaboration and sociality with other learners is difficult to reproduce in online learning environments. Moreover, distance learning requires learners to be more organised and self-controlled.

Learners often use synchronous online tools, such as Google Hangouts, Skype and other social group networks, to communicate and interact with their classmates and instructors. Many also use Learning Management Systems (LMSs), such as Moodle[1], which provide chat rooms, discussion boards, blogs and Wikis for interacting and communicating. VR environments can offer learners opportunities to use all of these and more at the same place and the same time, thus supporting learners in achieving a feeling of 'being there' in a face-to-face meeting. When educators use appropriate pedagogical methods, they are able to automatically communicate with various populations of students [157]. To ensure that all distance learners are supported, a range of applicable systems should be utilised [158]. In virtual environments, teachers may apply various pedagogical strategies to their education processes to enrich distance learners' learning, engagement and immersion. Real activities created to support learning effectiveness allow learners to acquire necessary skills and look up relevant knowledge as their learning progresses [159, 160].

According to Hiltz et al. [161], pedagogy has a direct effect on learning outcomes in distance learning. The outcomes of learning systems and the grounded theories of educational design cannot be separated. Thus, more empirical studies need to be undertaken to evaluate the implementation of theory-based educational design to enhance interaction and communication in distance learning and to improve interface design to achieve the objectives of learning activities [162].

2.5 Summary of the Research Problem

This chapter began by introducing the background of MR concepts, including VR, AR and augmented virtuality, as well as technical displays. It also presented an overview of HCIs from different psychological angles (i.e. presence, immersion and engagement) and discussed theoretical and technical effective studies on MR environments. Then, the chapter addressed

[1] https://moodle.com

pedagogical and educational aspects of learning while applying MR technologies. The investigation of the literature on collaborative MR and AR learning environments revealed several issues. First, there is little investigation for providing a conceptual architectural model that enables groups of users from different locations, at different levels of expertise, and using different VR and AR interfaces to collaborate and communicate on learning tasks in MR and AR spaces. Secondly, while various studies considered several psychological HCI factors, such as presence, immersion and engagement, in measuring the impacts of these technologies on teaching and learning settings and in games, there is still a lack of research exploring these technological interfaces for learners and teachers working in various collaborative different MR and AR learning scenarios. To overcome these limitations, this study aims to explore the use of MR and AR spaces in collaborative learning tasks and their effects on learning tasks, as introduced earlier in this chapter. Then, it seeks to investigate MR and AR frameworks and pedagogical theories to form a conceptual architecture for collaborative MR and AR spaces, which will be implemented as a proof of concept. This architecture is discussed in the next chapter.

Chapter 3

Adaption of AR-based Environments to the Mixed-reality Teaching and Learning Environments (MiRTLE+)

The previous chapter provided the background for this research topic and discussed related studies. It presented an overview of MR and AR concepts and their shortcomings in collaborative MR and AR learning spaces, as well as their impacts on learning and teaching settings from HCI and pedagogical perspectives. This chapter uses the introduced pedagogical theories and MR continuum theory to structure and form this study's conceptual architecture. It also addresses related theories of games and card games and considers their application to education as activities. Then, it describes the selected game-based activity (i.e. the Uno card game) as a learning task in this study's learning scenarios. This description is followed by a justification and an explanation of the MiRTLE+ conceptual architectures. The chapter concludes with a summary of the addressed points of related theories and the formation of our conceptual architecture.

3.1 Theoretical framework

The study illustrated in this thesis focuses on the design and evaluation of a collaborative MR learning environment. The theoretical basis for this study is influenced by and draws upon two distinct research fields, which are: theories of MR environments and human-computer interaction. In particular, the work is informed by the overlapping areas of the psychological theories of presence, immersion and engagement and by the design of effective game–based collaborative learning, as shown in figure 3.1 on page 44.

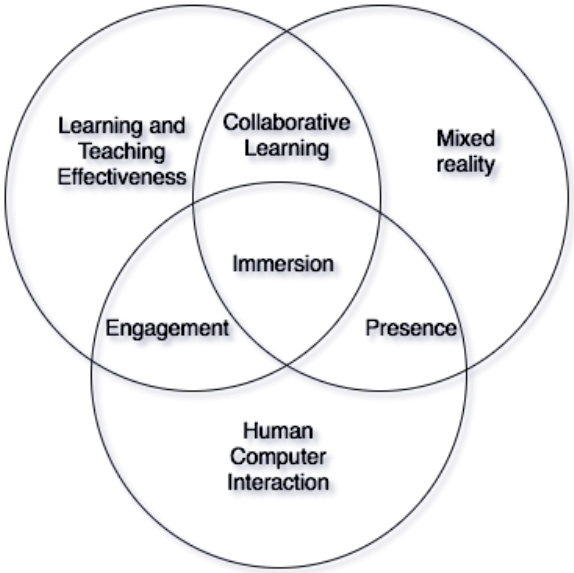


Figure 3.1: This study draws together the areas of mixed reality, human computer interaction, learning and teaching

This research also investigates a range of theories that relate to learning and teaching in MR environments (discussed in the literature review in Chapter two) and provides a pedagogical background for the use of games as effective learning tasks. It highlights the links between constructivist theories, including collaborative learning (e.g. [163]) and card games used as learning tasks. These pedagogical theories are also to assist structuring the framework of this study (i.e. how the technical framework would be effective in teaching and learning settings).

3.1.1 Learning theories

Constructivism learning theory

Constructivism argues that learners construct their own knowledge about a subject through active and engaged activity by building on past experiences and knowledge [164]. The constructivism view includes a number of theories and concepts. For example, social collaboration, one of the fundamental constructivism precepts, suggests that knowledge develops through social negotiation and through the advancement of the viability of learner comprehension. In this context, the social space is critical in the development of comprehension [165]. The constructivism view also proposes that learners learn by constructing their own opinions about the world through personal exploration and problem-solving. The constructivism view has heavily influenced the creation of learner-centred, interactive online learning spaces and tools [166, 167]. The constructivism learning space is also defined as "a place where learners may work together and support each other as they use a variety of tools and information resources in their guided pursuit of learning goals and problem-solving activities" [168]. These theories of constructivism and constructivism learning space are particularly important to this study because they form the foundations for this study, which is based on the use of a card game learning activity within a computer mediated virtual environment. For instance, a card game can provide opportunities for game learners to discover more advanced techniques for pursuing and achieving targets by building on basic knowledge provided by experts. Moreover, card game learners actively create their knowledge, instead of being just passive receptors of information [169]. In the cards games, the constructivism theory could be applied in a way that novices would have a basic knowledge of the card game rules before starting to play. Then, they can build their knowledge by making decisions in each game round and benefiting from previous experiences in the previous rounds.

Collaborative learning

The constructivist learning theory is founded on the core tenet of learners working together, sharing ideas, developing communication skills and learning from one another. Collaborative learning allows learners to develop their critical thinking ideas and creativity, and to evaluate a range of individual learning styles and skills and develop their strengths [170, 171, 172, 173].

Vygotsky [163], one of the known theorists of social constructivism, proposed the Zone of Proximal Development theory, which differentiates between what a learner can achieve when working alone and what s/he can achieve when guided or supported by a teacher or an expert, as depicted in figure 3.2 on page 46.

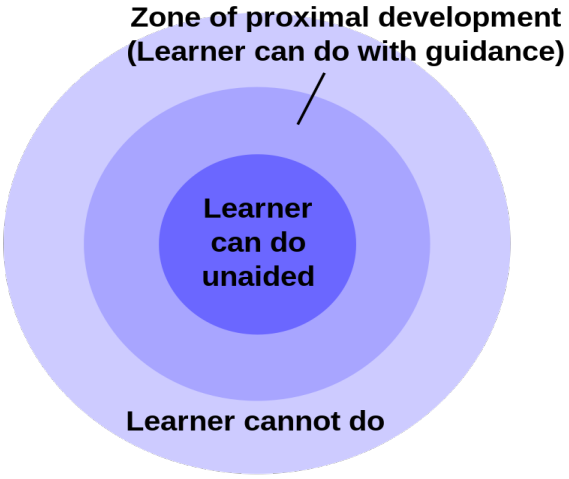


Figure 3.2: Zone of proximal development theory [163]

Collaborative learning is also defined as "a process of social construction of knowledge that takes place in the context of communities of inquiry" [174]. In a computer-supported collaborative learning (CSCL) context, knowledge is socially built and well supported through collaborations designed to help learners exchange knowledge and create artefacts incorporating features of group efforts and the use of various resources. This is the most widely supported approach at present, especially with regard to the use of technology [175].

In a collaborative learning environment mediated by technology, students can perform activities, and activities are mediated by artefacts accommodating both students and artefacts in the same place [176]. Thus, in terms of students, places and artefacts, the characteristics of

collaborative leaning environments in distance education involve four types of interactions: studentstudent, studentteacher, studentartefact and studentinterface [177]. Therefore, the design of these interactions, be it direct or indirect, can be formed by the CSCL environment, which this research takes into account.

Games and learning

It can be seen that games have an impact on learning, which is fundamental to the development of both adults and children [178]. Games promote a mastery of and engagement with developmental tasks [179]. One of the ways in which we learn is by playing. Play is a basic role of developing experiences of people, increasing chances to discover and practise in a safe environment and teaching such skills as timing, aiming, hunting and strategy [180].

Recent studies in the area of game-based learning have defined a game as an activity involving one or more gamers who seek to achieve a goal that has constraints, payoffs and results and is guided by rules and competition [181]. More specifically for education, games in computer-based learning are defined as "applications using the characteristics of video and computer games to create engaging and immersive learning experiences for delivering specified learning goals, outcomes and experiences" [182]. Using these definitions, Whitton [183] highlighted several game characteristics in her study framework for evaluating different types of games based on their activities, which can be more or less 'game-like' (as presented in Table 3.1 on page 48). These characteristics can be used to identify activities whose characteristics lead to more game-based learning activities.

Table 3.1: Characteristics of game-based activities [183]

Characteristic	Definition
Competition	Where the goal is to achieve better than other people.
Difficulty	Presentation of tasks that require effort.
Exploration	A context-sensitive virtual environment.
Fantasy	A make-believe environment or story.
Goals	Explicit aims and objectives, with a clear purpose.
Interaction	Feedback from actions and changing state of play.
Outcomes	Measured results from game play (e.g. scoring).
People	Other individuals playing the game at the same time.
Rules	Boundaries of play, limitations or constraints.
Safety	Lack of consequences of the game in the real world.

Learning through playing games can also provide more meaningful experiences through which learners' can be winning, losing and reviewing the game results [184]. The importance of these results to learners may encourage them to learn new concepts related to previous experiences [185]. Furthermore, when a game is used for learning, it can support the learners' development of their social, and emotional understanding [186].

Some types of cards games are competitive games that involve collaborative face-to-face learning, fun and enjoyment [169]. According to the game characteristics mentioned earlier, a card game may involve competition among players, clear goals, interactions, score-related outcomes, multiple users and rules. For our platform, we have selected the popular card game called Uno as our game-based learning activity for learners who have never played it before. The Uno card game was invented in 1970 by Merle Robbins. The game deck consists of 108 cards. Of these, there are 25 of each colour (red, green, blue and yellow). Each card for each colour is numbered zero to nine or labelled with one of the following instructions: 'Draw Two', 'Skip' and 'Reverse'. These last three cards are called action cards. The Uno deck also contains four cards each of two other action cards: 'Wild' and 'Wild Draw Four' cards [187]. The functions of these action cards are described in figure 3.3 on page 49. The objective of Uno is to discard one's hand before all other players to win the round. Then, the points associated with the cards left in each of the other players' hands are summed to

produce the score for the winner of the game round. The winner of the game is the one who is first to collect 500 points. To begin the game, each player is dealt seven cards. The rest of the cards are placed face down as a draw pile. The top card on the draw pile is placed face up. Then, the first player begins the gameplay by playing a card that matches the upward-facing card in the discard pile. Following the basic rules of Uno, the player can play a card with either the same colour, the same number or the same action as the card in the middle [187].



Figure 3.3: Action cards functionalities

Uno can be played by 2 to 10 players or by groups of two-partner teams. It is important to note that "...the Uno card deck itself are related to the interactive, multiple-player nature" [1]. For example, the action card 'draw two' requires the next opponent player to draw cards. White [188] developed an online web-based open-source Uno card game, which was modified and used for this study's game-based activity.

3.1.2 Milgram taxonomy

The Milgram taxonomy focuses on MR visual displays. In the Reality-Virtuality Continuum, as shown in 3.4 on page 50, MR can be divided into two components: AR and AV, in which the world is either mostly real or mostly virtual (computer-generated), respectively. The two extremes at either end of MR continuum are reality and virtuality (i.e. a world that is 100 percent real or 100 percent computer-generated). Thus, Milgram and Kishino [17] observed that the most straightforward way to view an MR space is one in which the real world and virtual world content are presented together within a single display (i.e. anywhere between the extremes of the Virtuality Continuum) [17].



Figure 3.4: Milgram's Reality-Virtuality Continuum [17].

The above figure defines 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).

3.2 An example scenario

Our practical work involves a mixed-reality environment that students (local and distant) can enter and log into online to join a a real smart classroom (i.e. the iClassroom at the University of Essex), as shown in figure 3.5 on page 51, and into a 3D virtual environment simulated in the iClassroom, as shown in figure 3.6 on page 52. The real iClassroom and the simulated 3D space (virtual iClassroom) have the following components:

- A table.
- Four chairs.
- Markers on chairs.
- Two iPads in the real iClassroom.
- Learning boards in the virtual environment.
- A PC on the real table.
- One pair of augmented reality glasses.
- One pair of virtual reality glasses.



Figure 3.5: A picture of the real iClassroom



Figure 3.6: A picture of the simulated virtual iClassroom

Learning scenario

Alrashidi et al. [189] proposed a 4D learning activity framework as shown in figure 3.7 on page 53 that structures learning activities from simple single learner discrete tasks to more complex group learning sequenced tasks. We use this framework to define the scope of learning tasks being considered for MiRTLE+. In our learning activity scenario, we thus focus on group learning with multiple sequenced tasks. Typically, this involves four students, two local and two distant, who work together to achieve the learning tasks being undertaken.

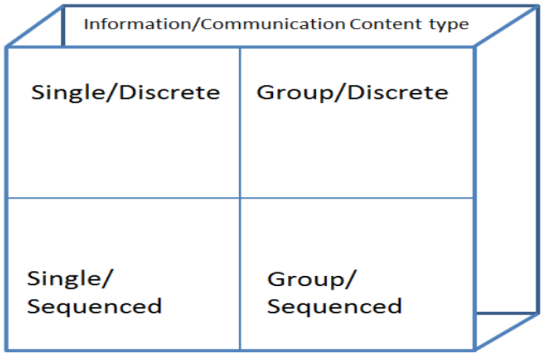


Figure 3.7: Four dimensional learning activity

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, people prefer to learn these types of games by being able to practice with experts whilst playing a real game. Thus, we use a learning-by-doing approach. As shown in the first layer of the figure 3.8 on page 55 The group is split into two groups of two expert and two novice students. This helps the novice learners who do not have any previous background or knowledge of playing the Uno card game to practice and play with their expert peers. 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.

Moreover, as the groups work together, a turn-taking coding approach will be considered as a key factor in our study to allow equal rights between members, since there is no teacher to decide who plays next and when. Thus, the software will enforce the turn-taking and controlled play; however, the expert from each team may also take over the turn when needed.

By mixing the group, the novice learners will start learning the game concepts by questioning experts and discussing the rules before playing the game for real. We examine the effect of mixing the novice and expert pairs across the different real and virtual spaces to explore how the virtual- and real-world dynamics affect the performance of the collaboration and the learning outcomes achieved.

3.3 MiRTLE+ architecture

Our research project is based on the original MiRTLE approach described earlier in Chapter two. However, in this study, we extend the MiRTLE approach to investigate more interactive and engaging techniques for merging local and remote learners within a real classroom setting. By using AR and MR concepts within MiRTLE, we integrate remote students (via their virtual representations) more closely with their local (physically present) counterparts. In so doing, we hope to enrich the learning activities within the MR learning environment and improve the collaboration and sharing between local and remote learners. We refer to this system as MiRTLE+.

Based on the aforementioned theories, learning scenarios and suggested frameworks of measuring presence and engagement in MR and AR spaces, we suggest a system architecture (shown in Figure 3.8 on page 55) to initialise our test bed environment, which is also used to deliver the learning content enhanced with collaborative AR and MR activities. Referring back to the aim of this study, our hypothesis (hypothesis 1) stated that it is possible to devise a conceptual architectural model capable of gathering a group of remote and local experts and novices into different learning scenarios, allowing them to exchange learning content in a collaborative, mixed-reality learning space. Therefore, this architecture has been structured and divided into six layers, some of which have components, as explained in the following points:

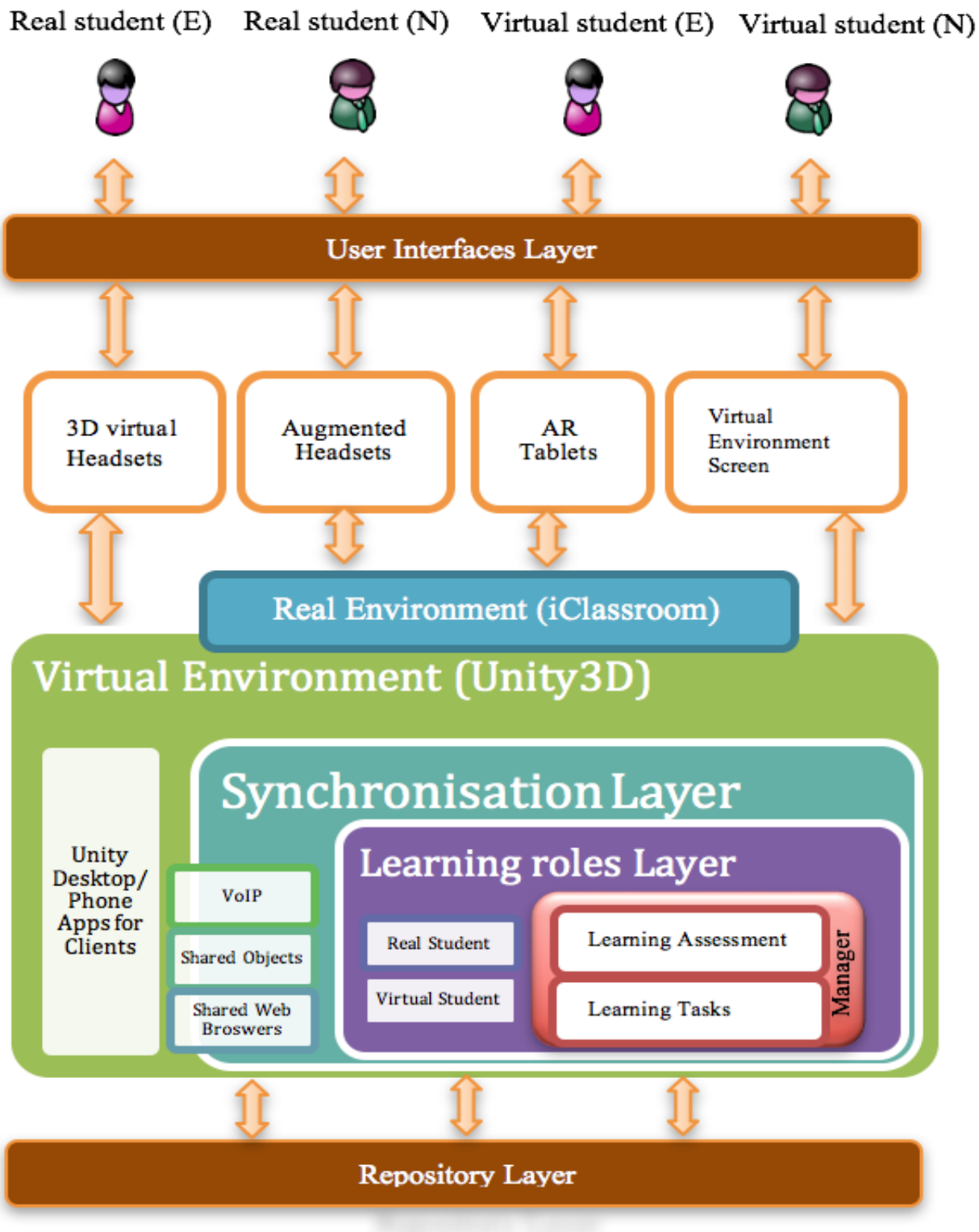


Figure 3.8: MiRTLE+ system architecture

1. *User interfaces layer:* Has various types of user interfaces. The main devices that are main the components of my research are detailed as follows:

(a) 3D virtual environment when using PCs and Oculus Rift glasses.

(b) AR view when using Tablets and Meta 1 glasses.

This layer allows students to communicate with the system through voice, face-to-face communications and object interactions.

2. *Real environment layer:* Is the physical space where the face-to-face collaborations occur. This layer comprises several objects: a smart board; a meeting table; markers; and chairs. This layer allows local students to communicate with remote students via AR technologies. This layer is the real iClassroom.

3. *3D Virtual environment layer:* Is a remote student interface, where remote students can meet with their physically present local counterparts. This layer simulates the real iClassroom in terms of its shape, shared objects and dimensions. Therefore, it contains a meeting table, chairs and smart boards, as well as avatars (characters) representing remote and local students.

   Part of this layer is:

   - The component of the user application interface: Its responsibility is to apply various interface layouts based on the device used.

4. *Synchronisation layer:* Is responsible for all processes and activities in our augmented and mixed reality space. This layer obtains all interactions and data changes among virtual and real students and updates students according to their user roles (e.g. allowing real students to see and interact with virtual students, and vice versa).

   Any changes in data can be distributed throughout our system via the components below:

   (a) Voice component: Is responsible for transporting voice over IP as binary data, which are then extracted and run using a supported package for client environments.

(b) Shared objects component: Has data representing the behaviours of each object (e.g. if a chair has a student on it or a smart board has an active communication dialog, etc.).

(c) Shared web browsers component: Is responsible for the content through which students can achieve learning activities in both real and virtual environments.

5. *User roles layer:* Is part of the synchronisation layer as its responsibility is to identify the roles for each user: real user, virtual user and manager (i.e. instructor).

   Based on his/her status (local or remote), a student will log into the system using a particular interface device and will focus on the process and activities needed for success, as exemplified by the following components:

   (a) Real students component: Allows the usage of AR tools and physical smart boards, objects (chairs, table and tags) and screens to display browsers in the real world.

   (b) Virtual students component: Allows the usage of all 3D virtual objects (e.g. web browsers textures, chairs, table and voice) in the virtual world.

6. *Manager layer:* Is part of the user roles layer. This layer contains two components, as follows:

   (a) Learning tasks instructor: Gives students instructions and learning content to begin and progress through the learning tasks. Its main objective is also to support and guide students as they achieve tasks.

   (b) Learning assessment component: Is responsible for receiving, processing and sending feedback on all students results.

7. *Databases layer:* Is responsible for communicating with the server and clients in order to store and retrieve users' roles, profiles, environment settings, learning content and feedback.

The structuring of the proposed MiRTLE+ architecture poses the challenge that the creation of a technical infrastructure is able to integrate real and remote environments to enable performing collaborative learning activities between physical and virtual users as well as objects in real-time. Thus, it is necessary to highlight the key dimensions that are required to create collaborative learning activities that involve the use of mixed reality systems. Lee et al. [190] defined three important dimensions for ubiquitous virtual reality (U-VR) that can be applied to distributed mixed-reality:

1. **Reality:** which refers to the point where the system is located in relation with Milgrams virtuality continuum [17].
2. **Context:** which refers to the flexibility to change and adapt according to time and space. Context can be displayed as a continuum ranging from static to dynamic.
3. **Activity:** which refers to the number of users that will execute an activity within the system, going from a single user to a large society.

Likewise, Alrashidi et al. [189] suggested a 4-Dimensional Learning Activity Framework (4DLAF) that can classify learning activities by number of learners and complexity of the task. Moreover, Rios [191] proposed a classification of learning activities to identify the affordances of their proposed Mixed Reality Smart Learning (MiReSL) model as shown in figure 3.9 on page 59.

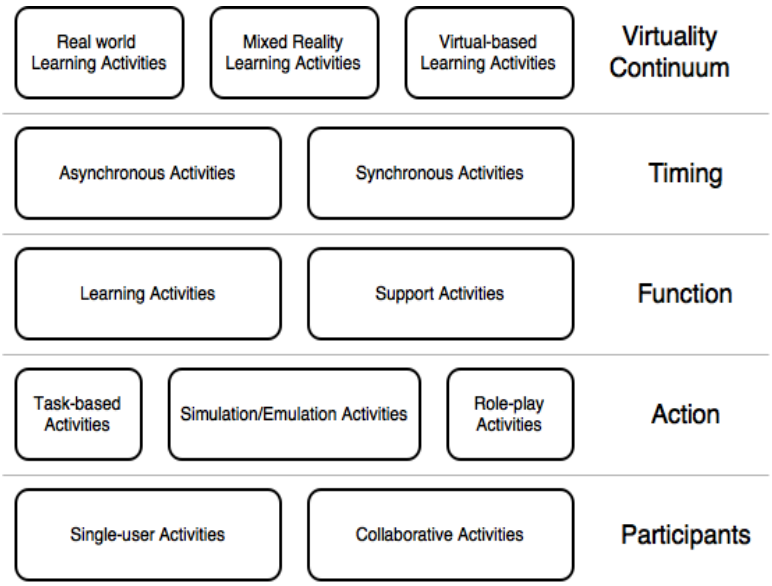


Figure 3.9: Classification of activities in the MiReSL model (MiReSL-LA) [191]

This MiReSL-LA classification is constituted by:

1. Virtuality Continuum-based activities classifies activities in base of their interaction with physical and virtual objects.

2. Timing-based activities refer to the time when activities are taking place. For example, synchronous activities involve the execution of activities between two or more participants at the same time (e.g. team-based collaboration); whereas asynchronous activities may be completed individually, (e.g. research, personal assessment, etc.).

3. Function-based activities refer to the nature of the activity itself. For example, if it is a main Learning Activity such as lectures or a Support Activity such as coursework.

4. Action-based activities refer to the main work being undertaken in the activity. Task-based activities are events that result in a deliverable. Simulation/Emulation activities involve activities with physical-virtual devices. Finally, role-play activities refer to role definitions performed within game structures and supported by co-creative rules.

5. By number of participants includes activities designed for an individual (Single-user activities) or for groups of people (Collaborative activities).

Based on the MiReSL-LA classification, the proposed MiRTLE+ architecture has the capability to provide learning activities that include the characteristics shown in figure 3.10 on page 60.

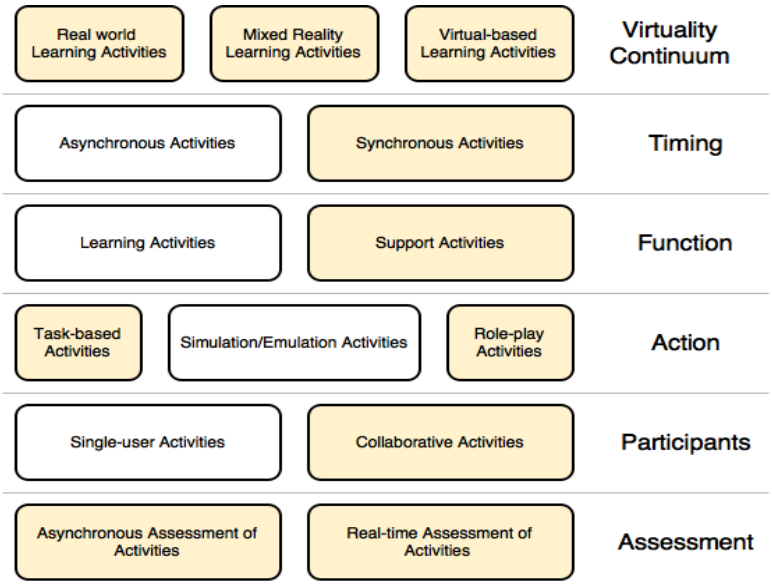


Figure 3.10: Classification of Activities in the MiRTLE+ model

In addition to the above mentioned classifications, the MiRTLE+ also provides a real time assessment that assists teachers (or experts) to evaluate students (or novices), as well as when novices check their progress. This is also contributed to the MiReSL-LA classification as shown in the last layer of figure 3.10 on page 60.

This architecture has been developed to support a synchronous collaborative group learning in mixed and augmented reality spaces using different interfaces for a simple informal game-based activity. Thus, in order to create collaborative learning activities that involve different level of expertise and location, the following design specification should be taken into account when utilising MiRTLE+ model:

- Type of learning, which refers to the form of the learning context whether formal learning (e.g. laboratory, practical classes) or informal learning (e.g. games, discussion, meeting).
- Content, which refers to the platform that presents the content of the learning activities

whether web-based content, AR virtual content, VR content or paper-based content.

- Environments, which refer to the environment that people/users work on. It can be range from real collaborated classroom to designed 3D virtual simulation.
- Assessment, which refers to the type of assessment whether instant feedback that is generated from the system or feedback that comes from experts.
- Interfaces, which refer to the interface devices that users can use to communicate with the system, which can be handheld devices such as tablets, smart phones, etc. or head-mounted displays such as AR glasses, etc.
- Collaboration, which refers to the number of people that participate in the learning task, which can have two or more participants.

In addition, the following table 3.2 on page 61 presents how MiRTLE+ expands MiRTLE in terms of pedagogical and technical perspectives.

Table 3.2: MiRTLE of being expanded to MiRTLE+

	MiRTLE	MiRTLE+
Pedagogy	Lectures	Class/Lab collaboration
Mixed Reality	Audio and video	Audio, video, objects and people
Devices	Screen-based	Screen, tablets, AR glasses and VR headsets

3.4 Summary

In this chapter, we have described the framework of this research. The chapter has considered the nature of our game activity and how it could be used to achieve learning objectives. Based on pedagogical and technical theories, our MiRTLE+ framework was also designed and explained. The next chapter addresses the implementation of building and deploying MiRTLE+ system and describes the experimental design to address the research questions.

Chapter 4

Experimental Framework

The previous chapter included the construction of the MiRTLE+ conceptual architecture based on mixed and augmented reality theory. It also involved some learning and games theories that were used for the MiRTLE+ learning scenarios. This chapter starts with the objective of using the Uno game activity as a learning task. Then, it describes the methods used and resources for implementing our proof-of-concept learning scenarios platforms, including a pre-survey of the Uno rules in two phases. Phase one involves the construction of a mixed and augmented reality environment (MiRTLE+), including all functionality described in our system architecture, using tablet and personal computer (PC) screens. Moreover, it involves the development of an error-based system for online open-source Uno card game activity. Phase two concerns the integration of additional user interfaces for the use of augmented reality glasses (Meta 1) and an immersive virtual reality headset (Oculus Rift). It is then followed by an explanation of the experimental design which was structured into two phases.

The objective of the game activity being applied in this study was to illustrate the concept and rules of the Uno card game. Novices learn the rules with their experts through several game rounds until achieving the target. Figure 4.1 on page 63 presents the support learning activity in the context of the IMS Units of Learning.

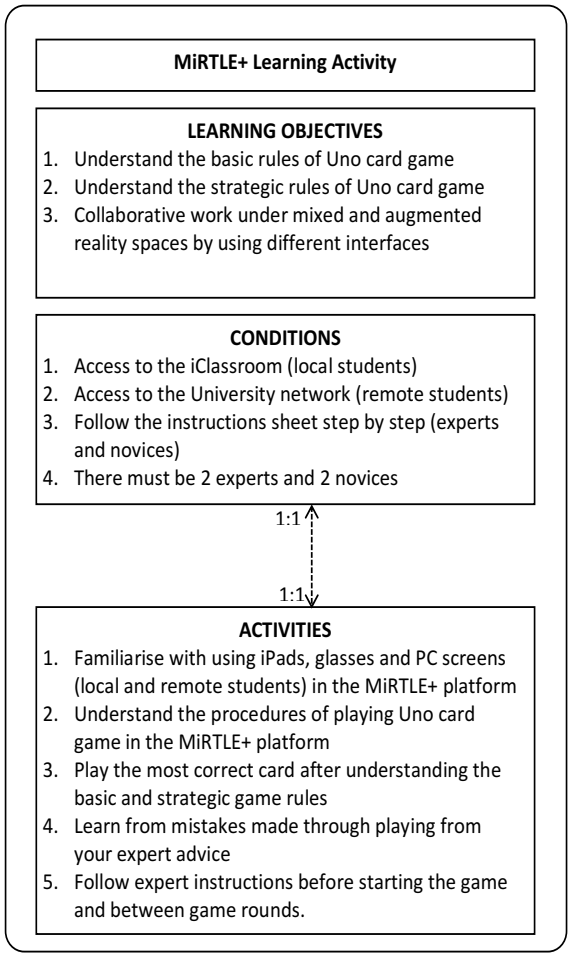


Figure 4.1: Unit of Learning - game activity used in our proof of experiments

4.1 MiRTLE+ platforms (implementation)

Our MiRTLE+ platforms were developed through two phases based on our system architecture described in the Chapter 3. The phase one was to construct the clients environments remotely and physically. These environments settings were based on tablets and PC screens. This phase also involved the development of our database as well as the servers. Also, the online open-source Uno card game, which was used as a learning task in our experiments, was also used and modified. In the phase two, the clients environments were modified to enable using immersive interfaces (i.e. Meta 1 glasses for the AR view and Oculus Rift headset for the VR view).

4.1.1 Phase one

The iClassroom at the University of Essex was used as a real space in our experiments that is where local experts and novices participate. In it, one table and four chairs with posted markers were set up and formed to meet the required layout for the working groups. The MiRTLE+ client platform was implemented using the Unity 4.6[1] (Pro) game engine, which supports C# and JavaScript routines. The Unity 3D platform was used because of its flexibility in building virtual spaces and its compatibility with and support of third-party packages and devices, such as the Meta 1 glasses. Some 3D and 2D models were built by using a SketchUp 3D[2] modelling computer program, and some other models were installed from the open source SketchUp 3D warehouse[3]. The client interface mechanism enables users to register and log into the 3D environment, sit down on an allocated chair, play from the in-world web-based game board and monitor their achievements, as shown in the following figures (4.2, 4.3 and 4.4) on pages 64, 65 and 65, respectively.

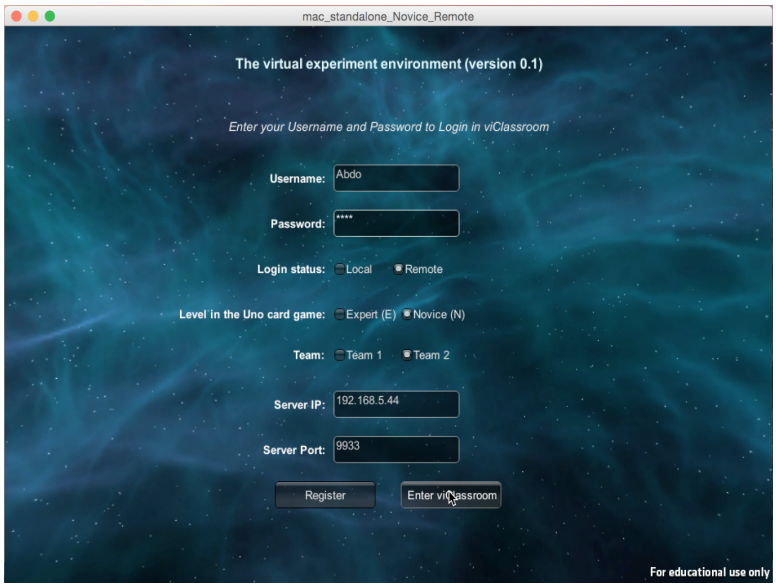


Figure 4.2: Login interface

[1]https://unity3d.com/
[2]http://www.sketchup.com/
[3]https://3dwarehouse.sketchup.com/index.html

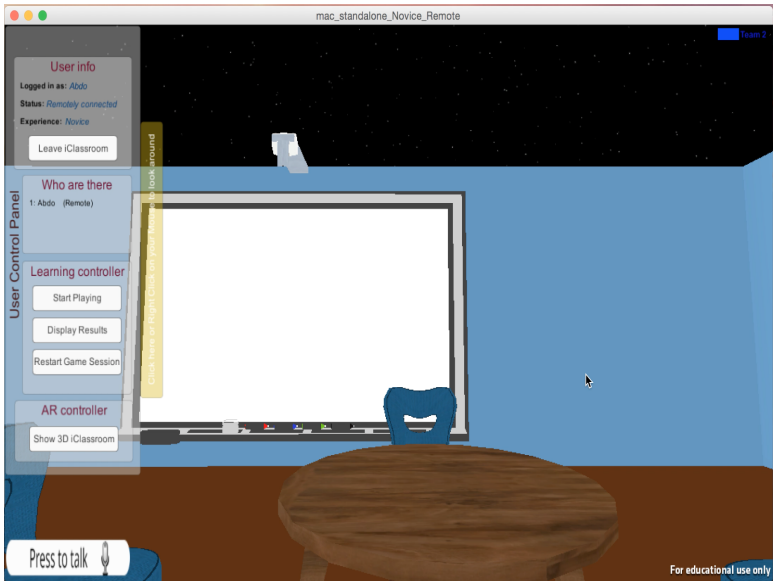


Figure 4.3: 3D objects in the environment



Figure 4.4: Cards game board

Augmented reality by using iPad interfaces was implemented using the Metaio SDK 6.0.1[1]. We used a natural marker-based object tracker, which is part of Metaio SDK with an example shown in figure 4.5 on page 66.

[1]Metaio SDKs are no longer available. As old subscribers, we still had our subscription active at the time of developing this platform

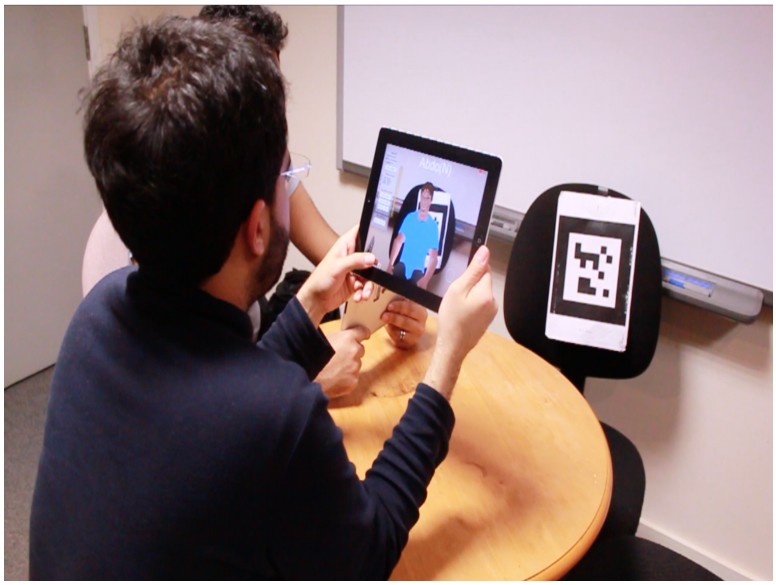


Figure 4.5: Marker-based augmented reality view in MiRTLE+

As shown on figure 4.6 on page 67, the server implementation was based on using a SmartFoxServer X2 (SFS2X)[1]. It is a middleware framework run using the Java language and XML schemes for real-time large-scale multiplayer games, massively multiplayer online games (MMO) and virtual communities. SFS2X supports APIs for connecting multiple clients to the server via a persistent connection (i.e. using the TCP/IP and UDP protocols). By using this connection, the server enables a synchronous interaction between users sitting on chairs, including their avatar actions/events and any communications events. To maintain a log to store the users registration, game sessions and time-stamped events, the MySQL[2] databases version 5.6.20 was implemented to communicate with the Unity clients. MySQL is the most popular open-source SQL database management system developed and supported by Oracle Corporation. However, a direct communication between a Unity client and a MySQL database would expose the database to possible security issues. Therefore, PHP[3] was implemented to enable the Unity client to communicate through Unity's WWW class to the MySQL databases using HTTP/TCP protocols. PHP is a open-source server-side scripting language for web pages. For the learning task, the open-source NodeJS-based Uno card

[1]http://www.smartfoxserver.com/
[2]http://www.mysql.com/
[3]http://www.php.net/

game developed by [188] was used and adapted for our learning evaluation as well. NodeJS[1] is an open-source JavaScript runtime environment for developing a diverse variety of tools and applications. NodeJS uses the WebSocket protocol, which enables a two-way connection between clients and the server over a single TCP connection [192]. This connection allows players to be notified about game events(i.e. current top card, cards left in each hands and whose turn it is). Moreover, our MySQL database also communicates with the NodeJS server through a node-mysql driver, which enables us to perform the usual CRUD[2] operations in the JavaScript files. Thus, the user logs are recorded whilst each player performs their actions.

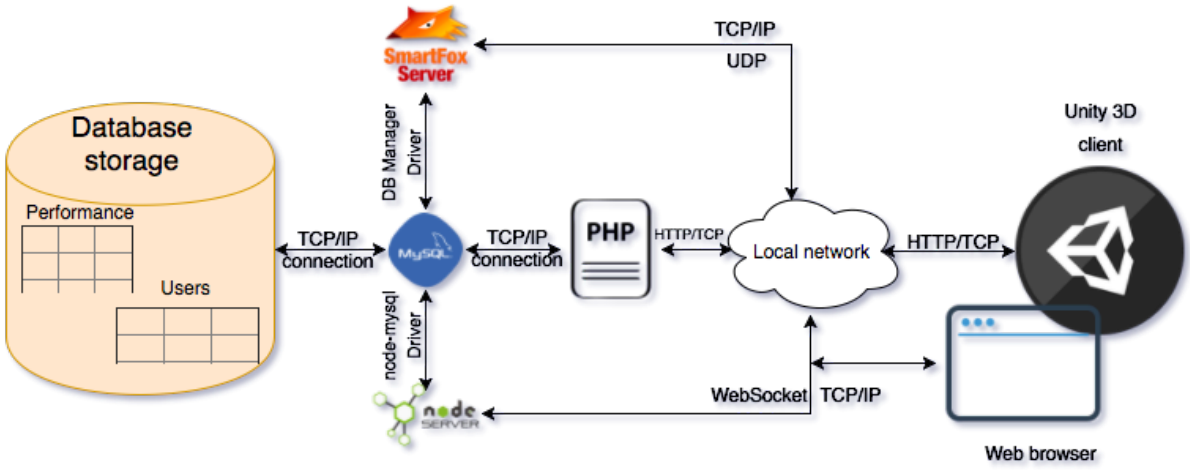


Figure 4.6: Server-clients based diagram for MiRTLE+

For the synchronous animations of avatars, our experiments only consider the movements of avatars on their chairs when they communicate to the left, front or right participant. For example, when the local participant from the real space points out to the marker on the right chair, his/her avatar's body synchronously moves to look at the right participant. Moreover, avatars can be distinguished in the virtual space by names of players, levels of expertise (i.e. N is for novice and E is for expert) that appear above each avatar (e.g. Ahmed (N)). Teams' cloths are also in different colours (i.e. blue for team one and red for team two).

[1]https://nodejs.org/en/
[2]Create, read, update and delete from the database

Two tables were mainly created for our database. The users' table named *users* was created to record basic information about users in the experiments (i.e. username, log-in time, team, location and learning scenario). The second table named *performance* was used to record every user action. This table contains the following fields:

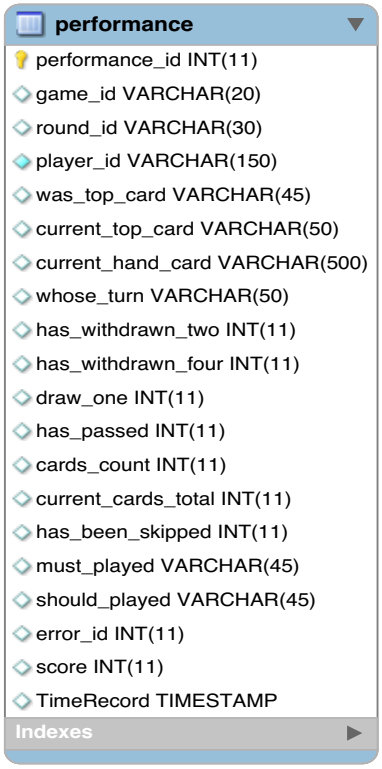
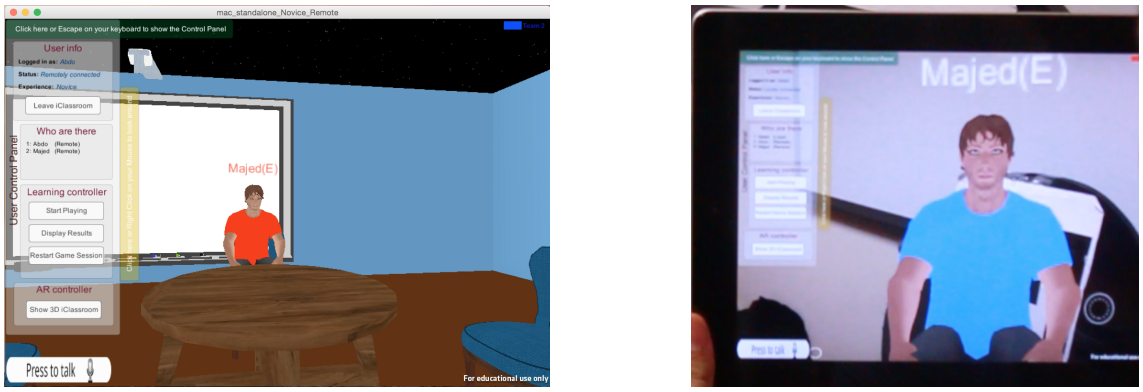


Figure 4.7: Performance entity from the database

Within the performance table, players' basic and strategic errors in the Uno rules were recorded. Basic errors were recorded in the *error_id* field as a number of the error code. For example, code 102 was recorded if the player did not play the matched colour or number card. Strategic errors were revealed based on our error-based system. For example, before a player played, our error-based system kept track of three parameters: the last played top card, the current player's hand cards and the count of the next player card. Thus, it generates two of the best highly recommended options (based on the player's cards), which were then recorded in the *must_play* and *should_play* fields. If the player did not play from either recommendation, it was recorded as a strategic error.

In the phase one experiment, two types of functionality for preparing virtual spaces for different interfaces were implemented. The first type is for a Mac and Windows stand-alone desktop application. This application enables remote users to login and interact with the virtual space objects through normal PC screens. The keyboard and mouse act as the controllers to move and look around, click buttons and play the game. Once the user logs in, they will be sat down on a specific chair based on the experimental preferences, and will see a virtual classroom simulating the iClassroom. The second implementation was for a mobile iOS application. In this application, users can also login and interact with the virtual space; however, it is through the AR interface. That is, once the user logs in through an iPad interface, the iPad camera is automatically started, and the user is able to see the real iClassroom with any other (virtual) users previously logged in and sit on chairs by pointing to the available markers on real chairs. Also, this user is sat down on a specific chair based on the experiment preferences as well, which enables remote virtual users to see him/her as well. The user controls the events through touchable buttons and joysticks. The following figures (4.8 a and b) on page 69 show both types of functionality interface.



(a) PC screen interface

(b) iPad interface

Figure 4.8: Implementation of 3D virtual spaces from different interfaces

Web browsers are implemented inside Unity client environments through different unity packages. UniWebView[1] package version 1.9.2 is used to integrate the web view to the mobile iPad clients. It enables the viewing of web pages and interacts with them through

[1]http://uniwebview.onevcat.com/

iOS or Android devices. Also, UniWebView allows users to communicate with the Unity scene, listen to web page events and interact with JavaScript. Another software package, uWebKit[1] version 2.0, enables the viewing of web pages through texture and 2D interfaces within stand-alone desktop Unity applications. Thus, it is used for our PC screen interfaces users. One technical issue with this package, which was encountered in our platform, was that it does not allow communication between standard JavaScript input dialog boxes and the NodeJS server. This issue was fixed by integrating the sweetAlert[2] jQuery library. The sweetAlert seamlessly provides a replacement for standard JavaScript dialog boxes.

Voice communication over IP is implemented by using DFVoic[3] package version 1.1a, as our platform deems voice chat as an essential component. DFVoic is a solution for multiplayer Unity voice communication and is integrated with the SmartFox server. The user is able to click and hold the *Press to talk* button, while other users can listen and see who is talking, as shown in figure 4.9 on page 70 below.



(a) Screenshot while pressing to talk



(b) Screenshot while listening

Figure 4.9: Voice communication in the MiRTLE+

In the developed virtual environment, a control panel on the left side helps user start, show and hide the game browser and to check who is available within the current session along with their level of expertise. It also enables and disables the function of looking around while playing. This control panel was implemented by using a Unity Graphical User Interface

[1] http://uwebkit.com/
[2] http://t4t5.github.io/sweetalert/
[3] http://daikonforge.com/dfvoice/

(GUI), as shown on figure 4.10 on page 71 below.

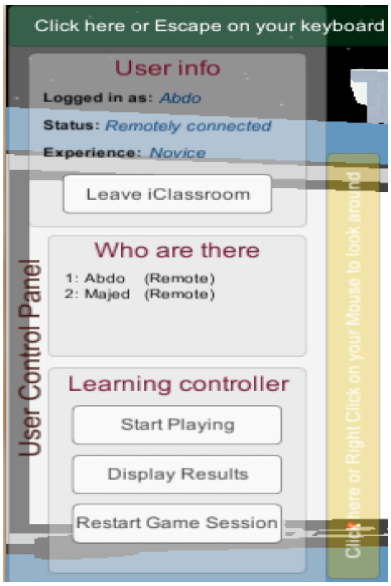


Figure 4.10: Control panel of end-user interface

4.1.2 Phase two

The second phase extends the first phase by adapting the user interfaces to use AR glasses and head-mounted displays in the MiRTLE+ platform (i.e. Oculus Rift glasses for remote users and Meta 1 glasses for local users), considering people's visualisation and their interaction with learning task on the web browser and communication through voice. As shown in figure 4.11 on page 72, Oculus Rift glasses are used in the MiRTLE+ platform for immersive VR views for remote users, and they are implemented on a stand-alone desktop application similar (as described earlier in phase 1) to the PC screen interface. However, some configurations need to be adjusted for a glasses interface. Firstly, the first person avatar camera is changed to the Oculus Camera, which is supported as a Unity prefab in their software package. Secondly, the elements of the users' GUI interface, such as the control panel, are rendered using the Screen Space mode, but for use within Oculus they need to be rendered using the World Space mode. Therefore, the buttons and other 2D objects in the virtual space are relocated in a more convenient place for the Oculus user view. Finally,

a gaze pointer is added using the functionally of the Unity's RayCast class to allow users interacting with the GUI interface to move other objects in the space by clicking on the space bar (or the mouse left button) to fire the actions. Due to the limitation (at the time of implementing this system) of Oculus Rift in supporting users in typing and seeing the keyboard at the same time, the user had to log in to the environment before wearing the glasses in our experiment. In Oculus Rift, the uWebKit package for the web browser is also implemented. However, the browser must be set as a texture, which allows the gaze pointer to interact with it.



Figure 4.11: Different angles of Oculus Rift implantation in the virtual iClassroom

We implemented the Meta 1 glasses in the MiRTLE+ for an immersive AR view for local users. As shown in figure 4.12 on page 73, the Meta 1 is developed and run as a stand-alone desktop application. However, it has a requirement that it can only be run and developed under a Windows 8 operating system or higher. Meta 1 also provides a Unity package to

integrate the glasses into the Unity project. Thus, the first person camera is changed to the Meta 1 Camera through their supported package. This step also considers the synchronous movements of other users of the Meta 1 user head while they look around. Moreover, all buttons and objects are reconfigured based on the Meta Graphical User Interface (MGUI). By doing this, MGUI objects can be touched and manipulated by a hand gesture. With regard to the web browser, the HoloWeb package developed by the Meta company enables users to interact with the web pages through typing or by gesturing on a virtual keyboard or typing and clicking using a real keyboard and mouse. Meta 1 supports a marker-less AR technique. Therefore, once other users log into the environment, their Unity components are changed to meet this requirement. Thus, those users can be seen by the Meta glasses user within the real iClassroom space.

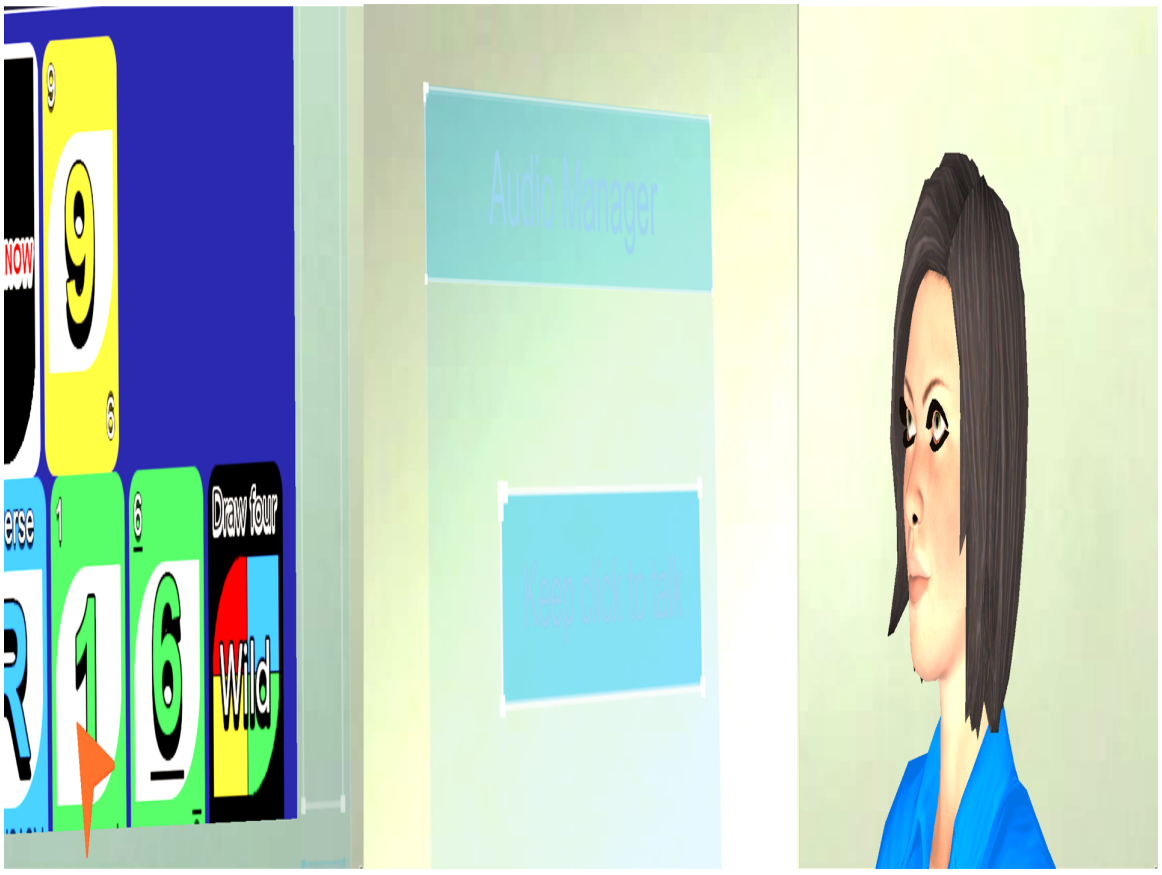


Figure 4.12: Different angles of Meta 1 implantation in the real iClassroom

The test bed Our test bed is the real and virtual iClassroom, where real students use

iPad tablets that are provided with our initial pre-installed application. The application has been built for our clients using the Unity3D game engine [183], which is a powerful cross-platform 3D engine and a user-friendly development environment. For real-time synchronous activities, we use the open-source SmartFoxServer [184], which is a comprehensive SDK for rapidly developing multiplayer games and applications with Unity, Flash and more.

In terms of augmented reality technology, the Metaio open-source version was used to accomplish virtual student visualisations (presence) in the real environment. Metaio is a privately held augmented reality company that develops software technology and provides augmented reality solutions [193]. Two of the features of the software that are used in this experiment are the ability to scan bar codes and QR codes, and it is deployed with iOS, Android, Windows PCs and Unity platforms. Comparing with other AR frameworks such as Vuforia, Metaio was widely applied by developers and it can be seen as a faster SDK for tracking 3D objects than other SDKs by the time of developing the platforms of this study.

The DFVoic package [194], which provides voice-over IP in Unity, has been used to allow communication amongst students in both real and virtual classrooms.

Using these platforms and packages has helped us to integrate the whole project to fulfil the technical requirements and to meet the research challenges.

An example screen from the prototype is shown in figures (4.13 and 4.14) on page (75 and 76) for a local student (Malek) and a remote student (Abdoo), respectively. Malek has entered the real iClassroom and has logged in to the virtual environment at the same time via the iPad. Then he has pointed to the left mark on the left chair and found his colleague sitting down with a blue t-shirt, as shown in figure 4.13 on page 75. Abdoo (virtually) could see and communicate with Malek on the other side of the table as an avatar and communicate with him using his microphone, as shown in figure 4.14 on page 75.

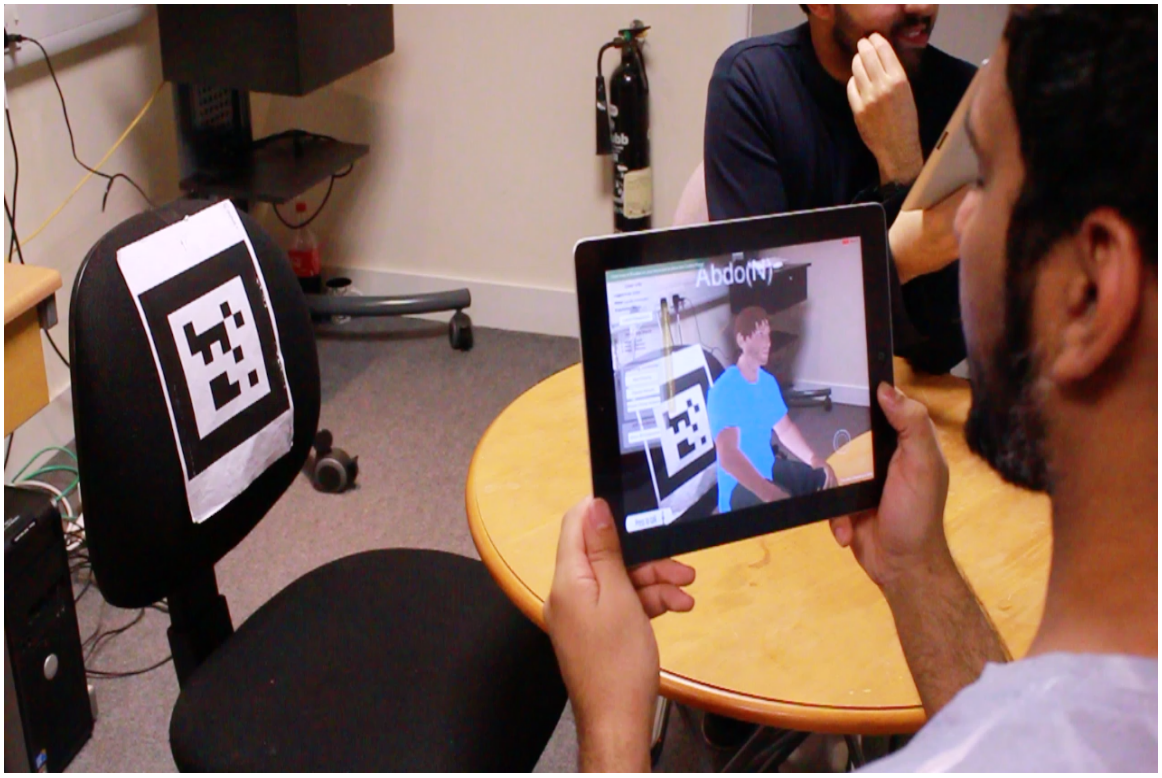


Figure 4.13: A screenshot when a real user communicating with the augmented user in the iClassroom



Figure 4.14: A screenshot where the virtual user by using his PC communicates with the real user (via his avatar)

By implementing MiRTLE+ based on our proposed conceptual architecture, we have supported our hypothesis 6.i, which states, *'It is possible to devise a conceptual model capable of allowing a group of students with different levels of expertise and at different locations to communicate, interact and collaborate on learning tasks by using different interfaces based on the concepts of mixed reality'.*

4.1.3 Required resources

The implementation of MiRTLE+ was developed and run by using the following hardware and software resources:

- Unity 3D
- 3D modelling applications (Sketch up)

- MiRTLE
- iClassroom (real environment)
- MySQL databases
- SmartFoxServer
- PHP language
- Java language
- NodeJS scripting language
- C# language
- Online card game
- JavaScript graphics APIs
- Markers
- Networking
- Android toolkit
- Oculus Rift glasses
- Meta glasses
- iPads
- Xcode 5

4.1.4 Evaluation techniques

The suitable choice of evaluation method for mixed reality technologies depends on the purpose of the evaluation. In our study, we observed three primary purposes: to show whether

or not our MiRTLE+ platform is beneficial to learning; to measure the user and teaching experiences with the MiRTLE+ platforms; and to explore the relative psychological factors of presence, immersion and engagement that may affect the learning outcomes. This empirical study compared the scores and levels of such factors between our MiRTLE+ platform and the control group (i.e. students collaborate and achieve tasks without the intervention of technology) as well as the web-based group (i.e. a traditional technical web-based platform). The most critical consideration in this type of evaluation is the execution of the control group. Therefore, the researcher must provide the best control possible [195]. For example, O'Shea et al. [196] created a game board version of the AR treatment group for the control group. To be more precise, the well-design control group can be used as a strong baseline to evaluate the experimental group in a comparison study. Therefore, the purpose is to provide evidence that specific factors (i.e. different users locations and interfaces and different levels of expertise in our experiments) in our experiments have an effect on particular outcomes (i.e. sense of presence, immersion, engagement and learning and teaching effectiveness in our experimental platforms) by comparing to our traditional control group.

According to Santos et al. [195], learning performance based on a knowledge test between treatment and control group is measured to compare the learning differences between the two groups. We applied a pre- and post-test for each learning scenario in our experimental phases. Moreover, the error-based system in the game system was used to observe the learners' improvement during the game, which also provided the data for the learning gains scores. Other factors related to the psychological experience (i.e. users' experience, teaching experience, presence, immersion and engagement) are commonly measured by a questionnaire instrument [110, 197, 198]. Therefore, we used a widely recognised and acceptable questionnaires by researchers for measuring these factors, as discussed in chapter two.

The surveys used in the experiments, which measured the factors related to the knowledge of the Uno rules, the user's sense of presence and immersion, and both pre- and post-tests

were designed by using SoGoSurvey[1] electronic survey software. One of its powerful features is that it allows the survey designer to include pictures in the question (stem) and choices for the multiple choices questions. Also, this software is cross-platform and enables participants to use their mobile phones or tablets to fill in the questionnaires with user-friendly interfaces.

4.2 Experimental approach

This section includes the experimental approach of this study used to answer the research questions described in the introduction section 1.4 on page 5. From the research questions, seven aspects were identified in order to carry out the experimental work: presence; immersion; engagement; learning effectiveness; teaching experience; users experience; and time to discuss and complete learning tasks.

Moreover, while subjective questionnaires are used for subjective feedback (presence, immersion and engagement), this section of the experiment also involves objective responses based on student achievements on learning tasks.

4.2.1 Pre-experiment Uno rules survey

To track novices' progress while they played the Uno card game, an error-based system was developed. This error-based system tracks each action made by the novice. For example, once the novice plays a wrong card or breaks a game rule, it is recorded in the database, and then the expert player or the experimenter can observe the novice's progress through a bar chart analysis for each error type.

All possible errors arising from playing the Uno card game were listed based on the Uno website, as presented below in the table 4.1 on page 80.

[1] http://www.sogosurvey.com/

Table 4.1: Errors in the Uno card game rules

Error in a rule
You cannot play now because
It is not your turn yet
Opponent player plays the skip card
Opponent player plays the reverse card
Opponent player plays Draw 2 or Wild Draw 4 card
It is not matched the requested colour by Wild card
You cannot play that card because it is
Not the same number
Not the same colour
Not the same shape (action cards)
You draw and you have a card
You pass without drawing
Try to draw more than one card
Levels of expertise in Uno
You do not say Uno when you have only one card
You do not follow a proper strategy by
Playing big cards before small cards
Changing to the most frequent colour
Not using the Wild Draw card when the opponent is almost finished
Choosing a wrong colour when playing the Wild card

People who have experience in playing Uno may to some extent expect that all the Uno rules are very simple for novices to learn from the first explanation of the rules of the game. However, we assumed in this research that the Uno rules (or errors) can be categorised into three levels: basic, intermediate and advanced (strategic). The basic and intermediate errors are straightforward rule conflicts, for example, when players try to play a different colour from the top card or when players try to pass their turns without withdrawing and so on. However, when a player has more than one option to play based on the current top card and the next player's hand cards, the action becomes more complicated. When a player does not choose the correct option, we call it a strategic error. For example, if the current top card is '5 Blue', the next player has three cards left, and the current player has two choices to play 'Wild Draw 4' or '9 Blue', they should play the card 'Wild Draw 4', since the possibility of the next player to finish and win is high.

To validate the aforementioned categorisation of errors and to apply them in our error-based system, a pre-survey was conducted among the participants who already knew Uno. The survey included two parts. The first part showed nine scenarios, and each of them were chosen based on random values for the next player's remaining cards (i.e. 3, 4, 5 and 7) in the Uno game; the player should take an action by ranking all possible cards they might play, as shown on figure 4.15 on page 81.



Figure 4.15: A screenshot from a random scenario

The second part contained the possible errors, as presented in the table below, to be categorised by Uno players based on three levels. This survey is attached to the appendix .2 on page 193.

Table 4.2: Errors statements to be categorised

No.	Error statement
1	If it is a player's turn, and s/he keeps asking 'Is it my turn now?'
2	If the player tries to play a card that does not match the colour or number
3	If the player calls for a colour on the Wild card that s/he does not have many of
4	If the player keeps passing the turn without withdrawing one card
5	If the player does not say 'UNO' once s/he has only one card left
6	If the player usually plays cards carrying small numbers before cards carrying big numbers of the same colour
7	If the player does not play Draw 4 or Draw 2 cards when the next player is about to finish
8	When the player does not play a card that has the same number but a different colour which s/he has a lot of

For this pre-survey, we recruited participants through social network applications (WhatsApp and Facebook). In total, 163 participants (78 female and 81 male) fully completed the survey. Most participants were aged between 16 and 40 years old. Forty-six participants provided partially answered questions. However, we report only the results from the completed responses.

The following two bar charts show the results of the aforementioned pre-survey. The chart on figure 4.16 on page 83 illustrates the previous eight error statements numbers with the participants' ranking responses based on the use of the basic, intermediate and advanced levels. The majority of participants responded that these errors statements were basic for the errors' statement numbers (1, 2, 3, and 5), intermediate for numbers (4 and 6) and advanced for numbers (7 and 8). As the differences between basic and intermediate were very small in statements numbers (4 and 6), we decided that our error-based system would include only two levels: basic and advanced (strategic).

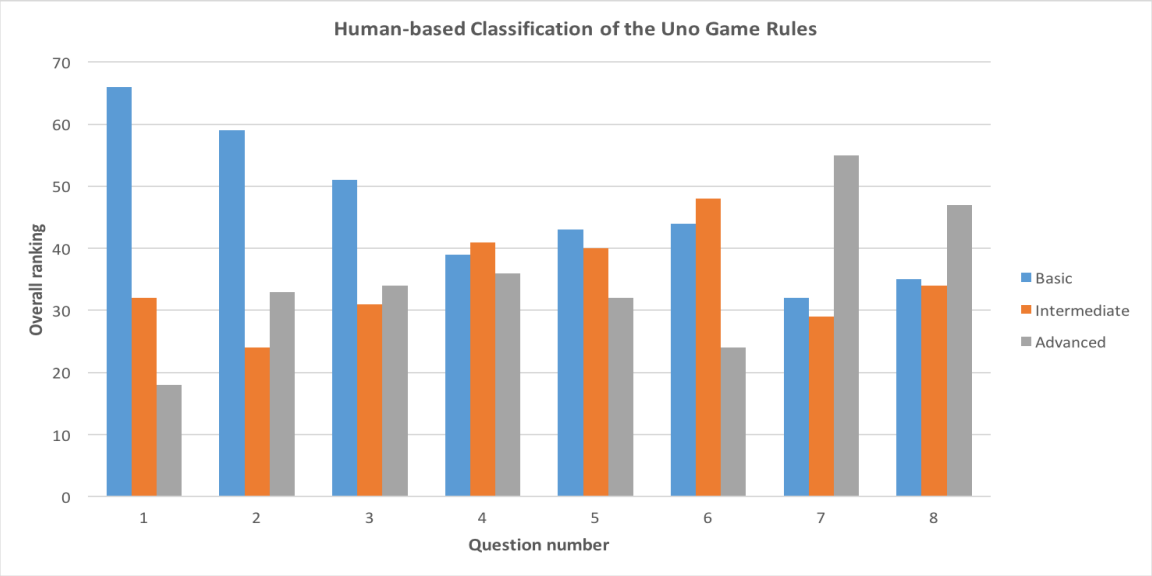


Figure 4.16: Classification of the Uno game rules based on human players

The chart shown on figure 4.17 on page 84 displays the ranking of which action to take based on the current hand of cards, the next player's hand of cards and the top card, as described previously. These actions include playing the highest value card (when the player plays the biggest value regardless of its colour), the highest colour (when the player changes the colour that s/he has a lot with a lesser value), the Wild Draw 4, a colour change (when the player plays a Wild card to change colour) and any same colour or value (without considering the biggest value) and withdrawing a card.

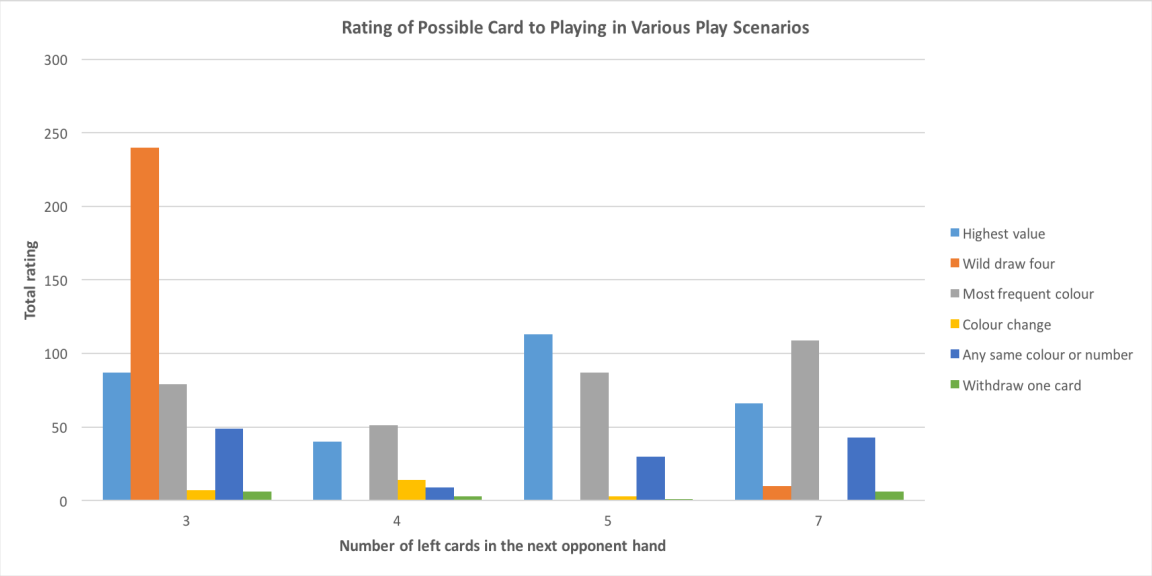


Figure 4.17: Actions of players to random game scenarios

When the next player has only three cards, in most scenarios, the most prioritised cards to play are Draw cards. Therefore, we have chosen the number 3 as a threshold at which a player must play a Draw (if it suits the current top card colour or value) or Wild Draw 4 cards if s/he has one of them. Moreover, the most frequent colour with the highest value has the highest priority in cases where the next player has four or more remaining cards. Also, the highest value card, regardless of its colour, has the priority in those scenarios in which the next player has four or more remaining cards. Our error-based system is built on these given scenarios.

4.2.2 Phase one

Subjects

Twenty-four participants voluntarily participated in phase one, 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. The arrangements with participants

were made through email and by using the Doodle[1] website. Participants included four females and 20 males. They were over 18, as had been agreed upon in the ethical application 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. In one scenario, only three participants appeared (i.e. two experts and one novice). Therefore, they were excluded from the study.

The participants from different levels of expertise were recruited from different locations in each scenario using the MiRTLE+ platform, as depicted in figure 4.18 on page 86. The first scenario from the left side had a team in a red rectangle, who played in the real classroom, and a team in a blue rectangle in the virtual environment. The second scenario had the red team with the expert in the virtual classroom and the novice in the real classroom, and the blue team had the expert in the real classroom and the novice in the virtual environment, and so on for other scenarios. Participants in the iClassroom at the University of Essex were considered local, and participants connected to the virtual classroom from room 5A.525 and room 5A.521 at the University of Essex were considered remote, as these rooms were connected to the iClassroom wireless network.

[1] http://doodle.com/

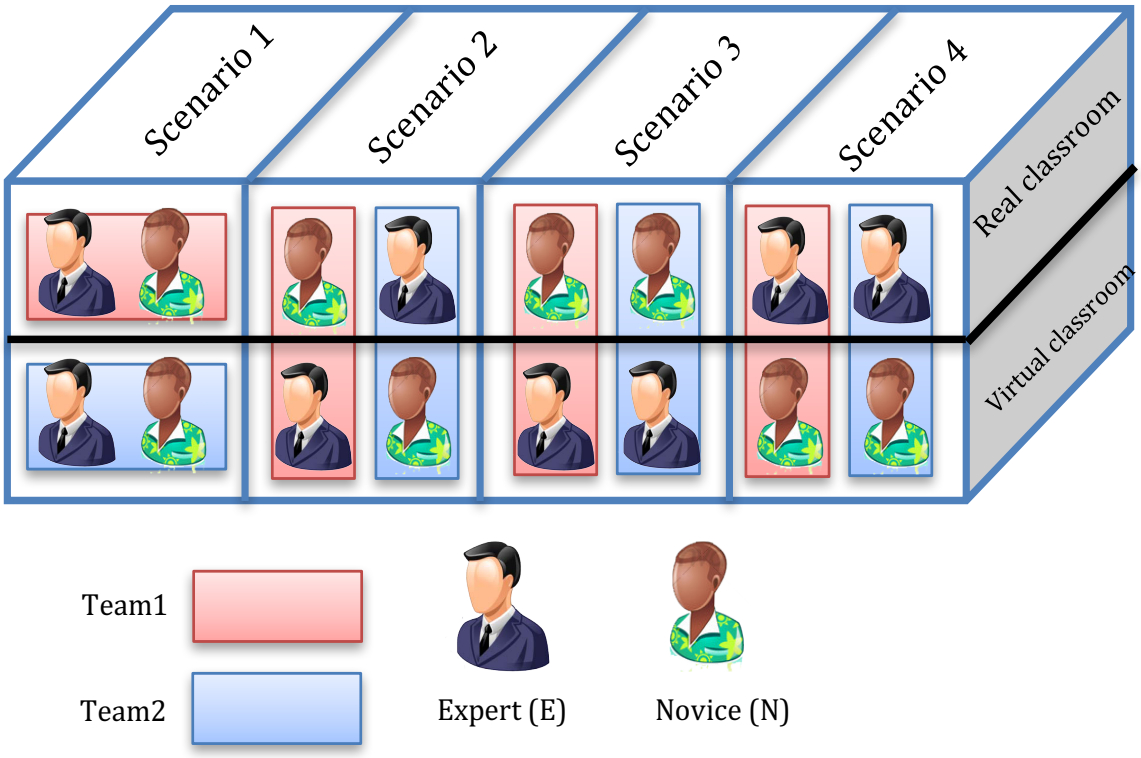


Figure 4.18: Learning scenarios - phase one

In the control group, four participants were recruited to play in the iClassroom without using any technological interfaces. The web group participants were recruited to play from their offices (which were separated from each other around the university campus). However, one expert from the web group was recruited to play from the iClassroom to enable the experimenter to follow up on the experimental procedures.

Variables

In phase one, the independent variables were the learning scenarios (as described above), user interfaces (i.e. VR on PC screens, iPad interfaces, Web interfaces and the control group), locations (i.e. remote or local) and levels of expertise (i.e. expert or novice). The dependent variables were the participants' sense of presence, immersion, engagement, learning effectiveness, user experiences, experts' teaching experiences, and the time taken for the learning and teaching activities.

Apparatus

Two iPad 2 tablets equipped with a 1 GHz dual-core Apple A5 processor, 512-MB RAM and an iOS 7.0.4 operating system were provided in the iClassroom to be used by the local participants. A MacBook laptop equipped with a 2.8 GHz Intel Core i7 processor, 16-GB RAM, and OS X Yosemite operating system was used as a server. Two Dell PCs equipped with a 3.10 GHz Intel Core i5-2004 CPU, 4-GB RAM and 64-bit Windows operating system were used for the remote participants. Four marker sheets (i.e. from number 1 to 4 based on Metaio documentation) were set up on the iClassroom chairs to support the augmented reality views. A real Uno card game was bought for the control game scenario. Two video cameras were set up to record the control game scenario. An iPhone 5s mobile phone was used to record the time by using the timer app. A Canon camera was used to record photos during the experiments.

Tasks and procedures

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.

MiRTLE+ learning scenarios

Once recruited, participants were kindly asked to sign the consent form. Before starting, there was a training session consisting of the following phases: phases:

- Warm up: participants received assistance about their instructions sheets for navigating the allocated environment, and the game board were provided and exemplified.
- Assigned task: participants were instructed who should start to talk and when during the game rounds based on the provided instructions sheets as well.

- Expert roles: two experts were given a sheet to recap the Uno card game rules based on information from the Uno website. These rules were then discussed beforehand.

In each scenario, experts were also provided with the experiment game rules and a sheet to follow the instructions for logging into the game environment (i.e. experts taught and discussed the rules with participants before starting the game session and between the game rounds). The novices were also provided with a sheet that included the instructions for logging into the game environment and their roles (i.e. novices could ask questions only before starting the game session and between the game rounds - see the appendix for the instructions sheets used on pages 207–215). Local participants (whether novices or experts) were given iPads, whereas the remote participants used the available PC machines in their rooms. Then, participants were asked to wear headset speakers, which also contained microphones.

Participants in the immersive virtual environment interacted with the scene from outside as if through a window rather than from an egocentric point of view; their bodies appeared to be located within the environment. This way is also called first person control (FPC)

With regard to the game-based learning task, the target was to win by collecting 300 points. It was limited to 300 points due to time constraints. These points were calculated such that the participants who discarded their cards before others in the round would obtain the points (i.e. the total summation of each others' remaining cards). The game turn was in an counter-clockwise direction, and the participants sitting order on the table was as follows: expert-team-1, then expert-team-2, then novice-team-1 and then novice-team-2. The experimenter observed all quantitative measurements (time and number of rounds). The novices' errors were detected during each round and logged into the databases. During the participants' game session, the experimenter sent the post-questionnaires to the participants to be filled in electronically directly after the experiment.

The presence and immersion questionnaires were sent to all four participants in each MiR-TLE+ scenario. The post-test was sent to the two novices, and the teaching experience survey was sent to the two experts. All participants also filled in the hard copy question-

naires used to measure the engagement and user experience variables. All questionnaires were completed. Finally, participants were sincerely thanked for their participation in the experiment.

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[1] 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.

4.2.3 Phase two

Subjects

Sixteen participants were recruited for the phase two experiment. The participants were recruited from the University of Essex through an opportunity sample. The arrangements to facilitate participants' availability were made through their emails and by using the Doodle website. Participants included four females and 12 males. They were over 18, as had been agreed upon in the ethical application form. Eight participants who had never played the Uno

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

card game and did not know its rules were recruited as novices. The other eight participants, who had played Uno and knew its rules, were recruited as experts. The participants were recruited in groups for each of our 4 learning scenarios. Each scenario had four participants playing in two teams. Each team had a novice and an expert.

Four participants were recruited for each learning scenario, as shown in figure 4.19 on page 90. The participants wearing glasses in the figure below used immersive glasses within their environments. On the left side of the figure below (Scenario 1), the red team wore glasses that are immersive AR glasses for the novice in the local classroom (i.e. iClassroom), and immersive VR glasses are for the experts in the virtual classroom. In the second phase, the AR and VR glasses were allocated for novices of both teams in the local classroom and virtual classroom, respectively, whereas one expert used an iPad interface in the local environment, and the second expert used a PC screen interface in the virtual environment.

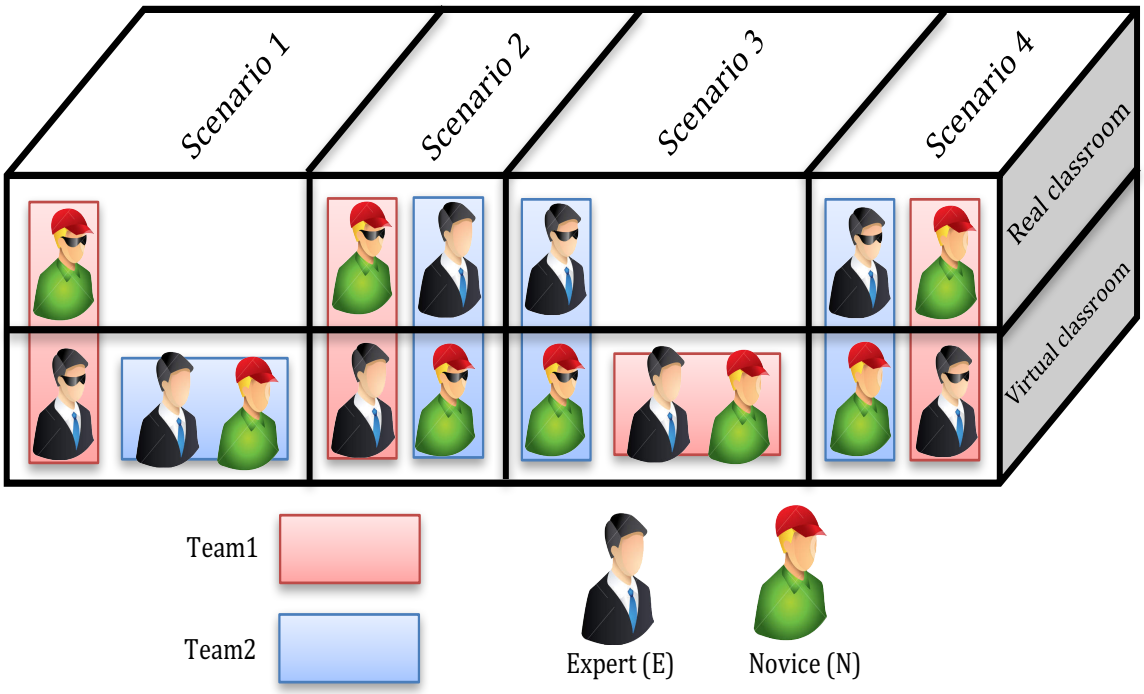


Figure 4.19: Learning scenarios - phase two

Variables

In phase two, the independent variables were the learning scenarios (as described above),

user interfaces (i.e. VR glasses interfaces, AR glasses interfaces, Web interfaces and control group), locations (i.e. remote or local) and levels of expertise (i.e. expert or novice). The dependent variable were the participants' sense of presence, immersion, engagement, learning effectiveness, user experiences, experts' teaching experiences, and the time taken for the learning and teaching activites.

Apparatus

The Oculus Rift DK2[1] virtual reality headset is equipped with OLED display, 1080×1200 resolution per eye, a 90 Hz refresh rate and 110° field of view. The integrated headphones provide a 3D audio effect and rotational and positional tracking for VR remote participants.

The Meta 1 [2] augmented reality headset equipped with 3D see-through display, 960×540 pixels (qHD) per eye, FOV expander lens (with a 35° field of view) and shade lens (with a 23° field of view), integrated Dolby 3D surround audio with built-in Electret microphones and head tracking, and a 320×240 (QVGA) pixel resolution 3D time-of-flight depth camera with 360° tracing was used for AR local participants.

A Mac mini PC equipped with a 2.6GHz dual-core Intel Core i5 (Turbo Boost up to 3.1GHz) and a 3MB on-chip shared L3 cache processor, 8GB of 1600MHz LPDDR3 memory RAM, and a Windows 8.1 operating system was used for running the Meta 1 glasses. A MacBook laptop equipped with a 2.8 GHz Intel Core i7 processor, 16-GB RAM and OS X Yosemite 10.10.3 operating system was used as a server.

Tasks and procedures

During the setup phase with the participants, the pre-test of the Uno card game rules and the demographic questionnaire which recorded their technology background was completed via email. The experimenter allocated four participants, two experts and two novices, in

[1] `https://www3.oculus.com/en-us/dk2/`
[2] `https://dev.metavision.com/sdk/assets/User_Manual.pdf`

each learning scenario based on their availability by using the Doodle website.

MiRTLE+ learning scenarios

Once recruited and instructed in terms of how to see their remote partner, participants were kindly asked to sign the consent form. In each scenario, the two experts were given two paper sheets: the first sheet was to recap (in 3 to 5 min) the Uno card game rules (which they were instructed to read silently) based on information from the Uno website, and the second sheet allowed them to follow instructions for logging into the game environment and provided the experiment game rules (i.e. experts taught and discussed the rules with participants before starting the game session and between the game rounds). The novices were also given one paper sheet that included the experiment game rules and the instructions for logging into the game environment (i.e. novices could only ask questions before starting the game session and between the game rounds - see appendix .3 on pages 203–206 for instructions sheets). The local participants (whether novice or expert) were given Meta 1 glasses and then were assisted by the experimenter in calibrating the glasses to their personal preference. The remote participants were also given an Oculus Rift head mounted display and then were assisted in calibrating the glasses to their preference. Due to the limitation of the available devices, two other participants in each learning scenario in phase two were recruited, similar to the process used in phase one (i.e. iPad tablets for local participants and PC screens for remote participants), and used the available PC machines in their rooms. Then, participants were asked to wear their headset speakers, which included microphones as well.

Participants in the immersive virtual environment interacted with the scene from outside as if through a window rather than from an egocentric point of view; their bodies appeared to be located within the environment.

With regard to the game-based learning task, the target was to win by collecting 300 points. It was limited to 300 points due to time constraints. These points were calculated such that the participants who discarded their cards before others in the round would obtain the points (i.e. the total summation of others' remaining cards). The game turns took

place in a counter-clockwise direction, and the participants sitting order on the table was as follows: expert-team-1, then expert-team-2, then novice-team-1 and then novice-team-2. The experimenter observed all quantitative measurements (time and number of rounds). The novices' errors were detected during each round and logged in the databases.

During the participants' game session, the experimenter sent post-questionnaires to the participants to be filled in electronically directly after the experiment. The presence and immersion questionnaires were sent to all four participants. The post-test was sent to the two novices, and the teaching experience survey was sent to the two experts. All participants also filled in the hard copy questionnaires for the engagement and user experiences variables. All questionnaires were completed. Finally, participants were sincerely thanked for their participation in the experiment.

The following diagram 4.20 on page 94 depicts our evaluation technique based on our studies variable, hypotheses and research questions:

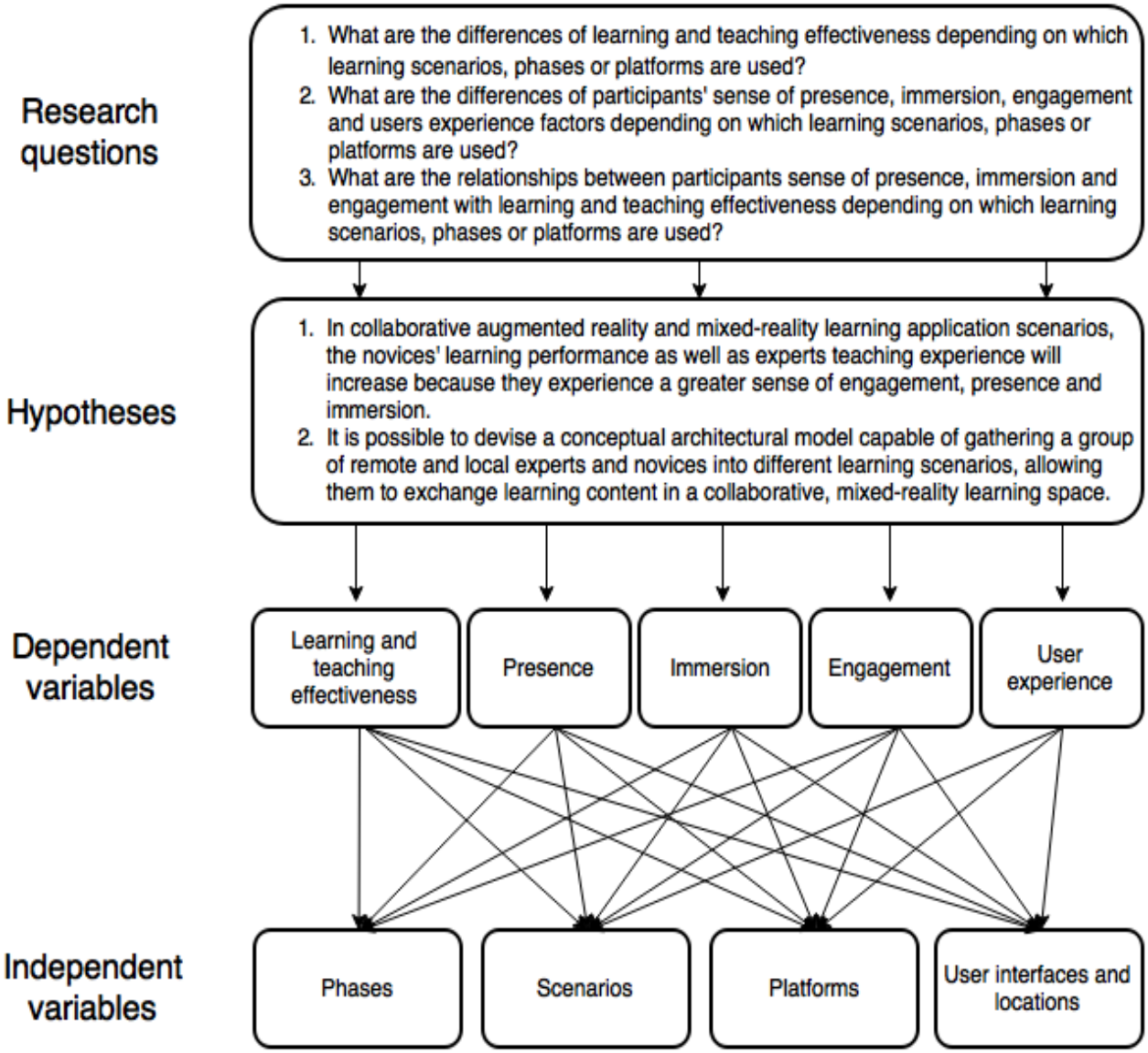


Figure 4.20: Evaluation technique in diagram

The overall hypothesis was reworded into sub-hypotheses to be statistically testable, as follows:

1. **Learning differences:**

   i) Novices with a high level of (a) sense of presence, (b) immersion and (c) engagement have better learning effectiveness scores (i.e. better gains scores).

   ii) Novices have better learning outcomes in AR-based and VR-based scenarios than a web-based scenario.

iii) Novices' knowledge of Uno rules improves as their trial errors decrease, in all scenarios.

2. **Presence, immersion and engagement differences between groups:**

   i) AR-based, VR-based, web-based and control groups show different levels of (a) sense of presence, (b) immersion and (c) engagement.

   ii) Novices and experts using AR-based and VR-based platforms (phases one and two) have better (a) sense of presence, (b) immersion and (c) engagement than novices and experts using the web-based platform.

   iii) Novices from the MiRTLE+ groups have better learning outcomes than those in the web group and their outcomes are similar to those of the control group.

3. **Presence, immersion and engagement differences between interfaces:**

   i) Users using AR-based interfaces (tablets) have a similar experience to that of the control group than novices and experts using web-based platforms and VR-based PC screens, in terms of the (a) sense of presence, (b) immersion and (c) engagement of the users.

   ii) Using AR glasses-based interfaces mimics reality (control group) better than using AR tablet-based interfaces in terms of the (a) sense of presence, (b) immersion and (c) engagement of the users.

   iii) Novices and experts using AR-based and VR-based glasses have a better (a) sense of presence, (b) immersion and (c) engagement than novices and experts who use VR-based or web-based interfaces.

   iv) The experience of novices and experts using AR-based and VR-based glasses is closer to that of the control group than the experience of novices and experts who use web-based platforms and AR-based tablets in terms of the (a) sense of presence, (b) immersion and (c) engagement of the users.

v) AR-based, VR-based, web-based and control groups experience a different (a) sense of presence, (b) immersion and (c) engagement.

4. **Presence, immersion and engagement differences between scenarios:**

i) Various learning scenarios of mixing AR-based with VR-based platforms, web-based platform and control settings result in differences in the sense of (a) presence, (b) immersion and (c) engagement of the users.

ii) Various learning scenarios of mixing AR-based glasses with VR-based glasses, web- based platform and control settings result in differences in the sense of (a) presence, (b) immersion and (c) engagement of the users.

iii) Scenarios involving AR-based interfaces (tablets/glasses) closely mimic the experience of the control group in terms of the (a) sense of presence, (b) immersion and (c) engagement of the users.

5. **Teaching experience:**

i) Experts using AR-based and VR-based interfaces respond more positively towards this technology than do experts who use web-based interfaces.

ii) Experts in scenarios using AR-based and VR-based glasses respond more positively toward the technology than do experts in scenarios using VR-based or web-based interfaces.

iii) Experts using AR-based tablets have better teaching experience than those using VR-based or web-based PC interfaces.

iv) Novices taught by experts with positive experiences have higher learning outcomes.

v) Experts with a strong (a) sense of presence, (b) immersion and (c) engagement have a better teaching experience.

vi) Experts using AR-based glasses respond more positively toward this technology

than those who use other interfaces.

6. **Conceptual model:**

   i) It is possible to devise a conceptual model capable of allowing a group of students with different levels of expertise and at different locations to communicate, interact and collaborate on learning tasks by using different interfaces based on the concepts of mixed reality.

7. **Users experience:**

   i) The levels of user experience-related factors are higher for MiRTLE+ scenarios than the web scenario.

   ii) The levels of user experience-related factors are higher for AR-based interfaces than the web interface.

   iii) The levels of user experience-related factors are higher for immersive glasses interfaces than for the web interface.

8. **Learning time:**

   i) Learning outcome gains among novices are higher when experts and novices spend more time on discussion within the learning activity.

The following two chapters present and discuss the findings of these sub-hypotheses.

4.3 Summary

This chapter started by describing the learning scenario that was used for our experimental work. Then, it showed the resources for developing this study's proof-of-concept implementation in two phases. Phase one was based on developing our MiRTLE+ platforms by using tablet and PC screen interfaces, conducting a pre-survey for identifying the levels of rules based on feedback from expert players, and developing an error-based system to track

novices' errors. Then, phase two integrated and developed the immersive glasses to our MiR-TLE+ platforms. This was followed by describing the experimental design, which included the samples, variables, instruments and procedures for each experimental phase. Finally, for evaluation purposes the original hypothesis was re-worded into the high-level premises to be discussed in the following chapters. The next chapter also reports on the results and analyses the outcomes from these experiments.

Chapter 5

Results and Analyses

The previous chapters described the related studies, theoretical and architectural frameworks and implementation and experimentation toward the development of the MiRTLE+ platform. This chapter presents the experimental results and analyses of our proof-of-concept MiRTLE+ platform, wherein the following factors were tested: sense of presence; immersion; and engagement; user experience; teaching experience; learning effectiveness; and task completion time. The chapter begins with an overview of collected demographic and technological background data. Then, we present the collected quantitative and qualitative data and the recorded times for the game task. The phase one and two experiment results are presented next, followed by the results of comparisons between experimental groups. Finally, the chapter ends by summarising the findings for all study variables.

5.1 Data collection

Demographic data

One of the research instruments used in this study was a questionnaire to collect general demographic information, assess the users previous knowledge on the evaluated learning tasks and the users' interest in mixed-reality technologies. This questionnaire is attached in

appendix chapter .1 on page 166. Data from this questionnaire was anonymised and analysed using the R language version 3.1.1.

Table 5.1 on page 100 presents the collected demographic information. In total, 32 male and 8 female subjects of a variety of ages (mean, 31 years) participated in phase one and two experiments.

Table 5.1: Demographic information of the sample

Variable	Number (N)	Percent ($\%$)
Gender		
Male	32	80
Female	8	20
Age		
18-20	1	2.50
21-25	5	12.50
26-30	9	22.50
31-35	21	52.5
36-40	2	5
Above 40	2	5
Qualification		
Undergraduate	5	12.5
MSc	6	15
PhD	29	72.5
Played the Uno cards game before		
Yes	18	45
No	20	50
Cannot remember	2	5
Knows the Uno cards game rules		
Yes	17	42.50
No	20	50
To some extent	3	7.50
Levels of expertise in Uno		
Expert	20	50
Novice	20	50
Scenarios		
Scenario 1 - 1	4	10
Scenario 2 - 1	4	10
Scenario 3 - 1	4	10
Scenario 4 - 1	4	10
Scenario 1 - 2	4	10
Scenario 2 - 2	4	10
Scenario 3 - 2	4	10
Scenario 4 - 2	4	10
Web scenario	4	10
Control group	4	10
Total	40	100

Most participants were PhD students (72.5%), while 27.5% were masters and undergraduate students, as shown in figure 5.1 on page 101. Twenty participants who never played the Uno card game and did not know its rules were recruited as novices, whereas 20 participants who had already played the Uno card game and knew its rules (or knew to some extent, 7.5%) were recruited as experts. Experts were also provided with a recap of the Uno rules in their instruction sheets before starting the sessions.

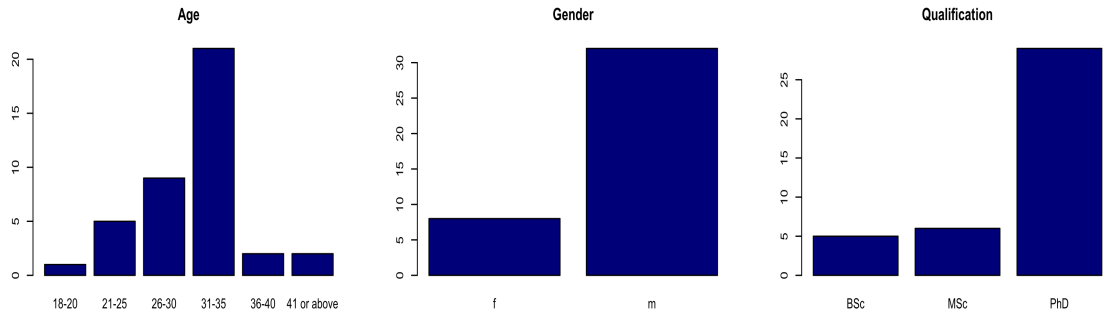


Figure 5.1: Demographic information bar chart

There were ten scenarios in two phases: six scenarios (including web and control groups) were carried out in phase one, while the remaining four scenarios were carried out in phase two as shown in the sub–figures (a-i) of figure 5.2 on page 102.



(a) Second scenario, phase 1 (b) Second scenario, phase 1 (c) Third scenario, phase 1

(d) Third scenario, phase 1 (e) First scenario, phase 1 (f) First scenario, phase 2

(g) Fourth scenario, phase 2 (h) Third scenario, phase 2 (i) Fourth scenario, phase 2

Figure 5.2: Participants in various MiRTLE+ learning scenarios

By developing and deploying our MiRTLE+ proof-of-concept platform that enabled collaboration between a group of students in different mixed and augmented reality learning scenarios, the hypothesis number 6.i on page 97 was supported - see chapter three for more details of the MiRTLE+ concept and architecture.

Participants' backgrounds

Participants' previous experience in terms of using these technical interfaces, mixed reality spaces and online cards games was collected in the demographic questionnaire. Table 5.2 on page 103 presents data from our sample's technological background. This data was collected as a means of analysing any secondary factors which might affect the differences between learners' learning outcomes within the different learning scenarios, interfaces and locations'.

Table 5.2: Sample backgrounds in terms of using technical interfaces and platforms

Variable	*Yes*	*(%)*	*No*	*(%)*
Played online games	27	67.50	13	32.50
Used AR technology before	9	22.50	31	77.50
Involved in MR space	10	25	30	75
Used flash games	23	57.50	17	42.50
Involved in immersive education space	7	17.50	33	82.50
Involved in a 3D space	13	32.50	27	67.50
Used immersive glasses	4	10	36	90

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 [199], namely, control, sensory, distraction and realism; (2) the Immersion Questionnaire (IQ), with its five factors identified by Jennett et al. [83], namely, control, challenge, real-world dissociation, emotional involvement and cognitive involvement; (3) the Game Engagement Questionnaire (GEQ), with its four factors identified by Brockmyer et al.[56], absorption, flow, presence, and immersion; (4) the User Experience Questionnaire (UEQ), with its five factors identified by Laugwitz et al.[138], namely, attractiveness, perspicuity, efficiency, dependability, stimulation and novelty; (5) the Teacher Technology Integration Survey (TTIS) by Vannatta and Banister[155], which identifies two of six constructors, namely, risk-taking behaviours and comfort with technology and perceived benefits of using technology in the classroom; (6) learning outcomes, which will be described further in the next paragraph; and (7) time taken to complete the learning tasks, as explained in time section 5.1 on page 108.

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.

Pre- and post-tests for novice participants were designed following the scientific approach described previously [200]. Both of these tests consisted of 10 multiple-choice questions to measure previous knowledge (i.e. Uno card game rules from simple to more strategic levels) before and after experiencing the MiRTLE+, control and web platforms. Moreover, the questions and choices were similar of both pre- and post-tests, but they were in different order. In order to validate the English language used in both tests, the questionnaires were checked by a native English speaker who was also experienced in playing the Uno card game and thus could suggest some rewording for most questions (e.g. question number 7) reworded to *'What is the purpose of playing a Withdrawing card (e.g., +2)?'* instead of *'What can Withdrawing card do?'* for clarity (see pre- and post-test sheets in appendix chapter .1 on page 179).

The error-based testing system attempted to detect novices' errors in understanding the Uno rules as they played using the various platforms. Error-based testing techniques were based on analysing the players' data records for any strategic errors and marking the players' records for any basic errors. Consequently, a database table was created to store these records, as will be discussed in the following section.

Database

The novices' playing behaviours were tracked and recorded in the database. Basic errors (i.e. not your turn and not the same colour; see section 4.2.1) were recorded in the database with the player name and error code. On the other hand, data on strategic errors, such as when the user did not play one of the recommended cards from their hand of cards, were extracted using SQL queries for basic and strategic errors, as follows:

Basic errors:

```
select count(error_id) from performance where player_id LIKE
\% n2 \% and game_id='s4' and error_id <> 0 and round_id=1;
```

Strategic errors:

```
SELECT was_top_card, current_top_card, must_played,
should_played, has_passed
FROM performance WHERE (error_id = 0)
AND (must_played = should_played AND must_played <> 'Withdraw')
AND (current_top_card <> must_played AND current_top_card <>
should_played)
AND player_id LIKE '%n1%'
AND game_id='s1'
AND round_id= 1;
```

Presence

The Presence Questionnaire designed by Witmer and Singer[199] was adapted for use in this research. This questionnaire includes 32 items using a seven-point scale to measure how compelling the participant finds the interactions with the virtual environment (i.e. 1 = 'Not compelling', 4 = 'Moderately compelling' and 7 = 'Very compelling') as detailed under the presence section in appendix .1 on page 170. For example a question was, *how much did your experiences in the virtual environment seem consistent with your real-world experiences?* Because we used this questionnaire in the MiRTLE+ groups, it was modified so as to better describe the type of presence provided in the AR-based, web-based and control-based environments.

Therefore, the presence scores were calculated from 1 (for not compelling) to 7 (for very compelling). All items were adapted by adding a 'not applicable' (NA) choice with a value of 8 in order for the questions to be applicable for all of the experimental groups (control, web, AR and VR). Moreover, some items were modified to suit the environment. For example, item 23 was modified from *'How involved were you in the virtual environment experience?'* to *'How involved were you in your environment (i.e. virtual environment, AR environment, real environment or web- based environment) experience?'*

As a result, items numbers 5, 6, 9, 12, 15, 16, 17, 20, 26, 28, 29 and 30 in the presence questionnaire also received 'not applicable' responses in the control group. Moreover, in the web group, item numbers 7, 10 and 18 received 'not applicable' responses. This, by design,

was expected. Therefore, the 15 above mentioned presence items were excluded from all of our analyses below. Thus, the mean values were computed for 17 presence items and designated as presence means (PMs).

Immersion

To compare the immersion levels between our study variables, we adapted and applied the IQ questionnaire constructed by Jennett et al. [83]. This questionnaire includes 31 items and uses a five-point scale to ask participants to rate from 1 to 5 how immersed they felt at the end of the game task (1 = 'not at all' and 5 = 'very much so'). The IQ was also modified to better describe immersion in VR-based, AR-based, web-based and control-based environments in terms that could be used in our evaluation. For example, item number 18 was modified from *'To what extent did you feel motivated while using the system'?* to *'To what extent did you feel motivated while playing in the augmented reality environment'?* The IQ scores were calculated based on a response of 1 for 'Not at all' to an immersion item and 5 for very (much, well, aware, difficult) or 'a lot'. In addition, all items were also modified by adding a 'not applicable' choice with a value of 6 so that the questionnaire could be applied across experimental groups. Questions 5, 13, 19, 26 and 27 were marked as 'not applicable' by the control group sample. Therefore, these items were excluded from our analysis. Moreover, the responses to items 5, 7, 8, 9, 16 and 17 were reversed, as they were worded negatively. Immersion scores were computed by finding the mean of participants' answers to all 26 questions and labelled immersion means (IMs).

Engagement

The engagement measurement computed in this research was based on the GEQ developed by Brockmyer et al. [56]. It includes 19 items and uses a five-point scale (1 = not at all and 5 = very much) to measure participants' levels of engagement after they complete the game task.

The GEQ was adapted for our study: 15 items that were more relevant to our conditions were used. The GEQ was administered to all participants, and engagement scores were calculated based on a response of 1 for 'not at all' to an engagement item and 5 for 'very much'. The mean value was computed for the 15 engagement-related items and designated as the engagement means (EMs).

Teaching

The TTIS [155] was adopted for our experimental conditions in order to measure experts' responses toward applying various interfaces (web-based interface, AR glasses, VR glasses, iPads and normal PC screens) in teaching. The survey includes 11 items that have a 4-point Likert scale of agreement (1 = strongly disagree and 4 = strongly agree). Teaching scores were determined by computing the mean scores for all participants' answers to all questionnaire items and designated as teaching means (TMs).

Video data

Video recording was used for the control condition, that is, when novice participants did not use technology while learning rules and playing. Therefore, two video cameras were set up in the real space (i.e. the iClassroom at University of Essex) to record the cards held by the novices as well as their top card. Figure 5.3a and 5.3b on page 108 present screenshots from the video record.



(a) First novice player (b) Second novice player with the top card

Figure 5.3: Screenshots from the control group video records

Time

Time was one factor used to measure its effects on learning in the experiments. It was collected by:

1. Manually using a mobile phone timer and a paper sheet.
2. Electronically adding a timestamp field to the database table (i.e. novices' performance table) to record the time at which users started and finished the learning tasks.

In all scenarios except the control scenario, the times taken to complete various rounds of the game were collected from the database records, whereas the corresponding times for the control scenario were collected from the video records. Then, the times were calculated by subtracting the start time from the end time for each round, as presented in Table 5.3 on page 109. Our aim regarding these time calculations was to investigate whether or not these times affected the learning outcomes. Moreover, these times were used to examine the differences between the various scenarios and the various MiRTLE+ interfaces.

Table 5.3: Summary of times taken to complete various rounds of the game in the different scenarios

	Time (*mins* : *sec*)						
	Round-1	Round-2	Round-3	Round-4	Round-5	Round-6	Total
Ph1 - S1	9:51	6:00	13:10	-	-	-	29:01
Ph1 - S2	10:44	10:53	5:12	-	-	-	26:49
Ph1 - S3	12:02	4:07	3:34	3:15	-	-	22:59
Ph1 - S4	15:45	6:10	8:58	-	-	-	30:53
Web	8:55	5:20	15:03	4:14	4:21	-	37:53
Control	5:19	4:30	5:31	9:10	4:59	2:15	31.44
Ph2 - S1	12:50	11:23	8:12	-	-	-	31:25
Ph2 - S2	9:40	13:05	6:28	-	-	-	29:13
Ph2 - S3	14:00	12:08	8:10	-	-	-	34:18
Ph2 - S4	13:15	10:08	4:22	10:57	-	-	38:42

Note: Ph stands for Phase and S stands for Scenario.

As seen from the above table, there were slight differences in the total number of tasks completed among all the scenarios. By using the control group time as the baseline, we found that the time taken to finish learning by achieving the target score was lower in the MiRTLE+ scenarios in phase one as well as in scenario 2 in phase two (which involved AR-based pads and VR-based screens) than that in the control group. However, these times taken by fully or partially immersed novices in scenarios 1, 3 and 4 in phase two were close to or higher than those in the control group as well as the web group.

In card games, luck in terms of the cards that are dealt also affects how quickly players learn the rules of the game (regardless of their skill). This was also observed in the present study, given that the number of rounds taken to win the game in each scenario varied considerably. Therefore, time may not be considered to play a key role in learning in our cases. However, as we already experimented with the same conditions for all learning scenarios and considered the same target score for winning the game by assuming that all scenarios roughly crossed through similar situations, the time differences observed may be affected by other factors, such as gesturing while wearing fully immersive glasses, as we will discuss in the next chapter.

Perhaps surprisingly, the total time taken for discussing the game rules before starting each

game and between game rounds (as shown in table 5.4 on page 110 below) did have an affect on the novices' learning gain scores. A Pearson's test has showed a positive correlation (0.32) between total time taken for discussing the rules and the mean learning gain scores in each scenario. These findings could support hypothesis 8.i on page 97 and are discussed later.

Table 5.4: Summary of teaching and discussion process times

	Time (*mins*)							
	Before	After-1	After-2	After-3	After-4	After-5	After-6	**Total**
Ph1 - S1	3:05	1:10	00:58	-	-	-	-	5:08
Ph1 - S2	3:32	1:45	00:55	-	-	-	-	6:12
Ph1 - S3	3:51	2:00	2:13	1:55	-	-	-	9:59
Ph1 - S4	2:25	3:04	1:15	-	-	-	-	6:39
Web	2:15	0:20	1:04	2:56	0:58	-	-	6:54
Control	3:00	2:20	2:44	2:17	00:55	0	-	11:16
Ph2 - S1	2:27	2:18	1:10	-	-	-	-	5:55
Ph2 - S2	3:05	1:51	1:05	-	-	-	-	6:01
Ph2 - S3	3:45	3:10	2:15	-	-	-	-	9:10
Ph2 - S4	2:06	1:35	0:01	0:58	-	-	-	4:40

Note: Ph stands for phase and S stands for scenario.

5.2 Reliability of questionnaires responses

In order to get an indication of the reliability and internal consistency of the questionnaires, Cronbach's alpha coefficient was calculated for each factor as shown in the table below. Table 5.5 on page 110 shows the results of the questionnaires' reliability in determining the presence, immersion, engagement and teaching constructs.

Table 5.5: Cronbach's alpha results for all dependent variables

	Cronbach's alpha
Presence	0.81
Immersion	0.83
Engagement	0.78
Teaching	0.82

As shown above, the reliability coefficients of all variables exceeded the critical value of

0.70 (i.e. 0.80 and 0.70), indicating that our questionnaires' responses have high levels and scientifically accepted levels, respectively, of reliability [201, 202].

5.3 Phase one experiment

As we explained earlier, this study focused mainly on the differences between MiRTLE+ interfaces within various learning scenarios. Table 5.6 on page 111 described the analysis of all scenarios in phase one. This table presents the means of all dependent variables (i.e. presence, immersion, engagement, learning outcomes and teaching experiences) based on the interfaces used in each scenario by experts and novices.

Table 5.6: Descriptive statistics for scenario-based interfaces - Phase one

	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
Engagement	3.96	4.14	4.04	3.64	3.57	3.68	3.82	3.82	3.20	4.12
Learning outcomes	10%	80%	30%	50%	45%	N/A	35%	N/A	35%	45%
Teaching experience	3.00	3.09	3.73	3.36	N/A	3.32	N/A	2.91	2.82	N/A

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.

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, 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, these findings do not support hypothesis 1.ii on page 94.

By monitoring novices' errors from the database as shown in figure 5.4 on page 112 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). We will discuss this finding in the next chapter.

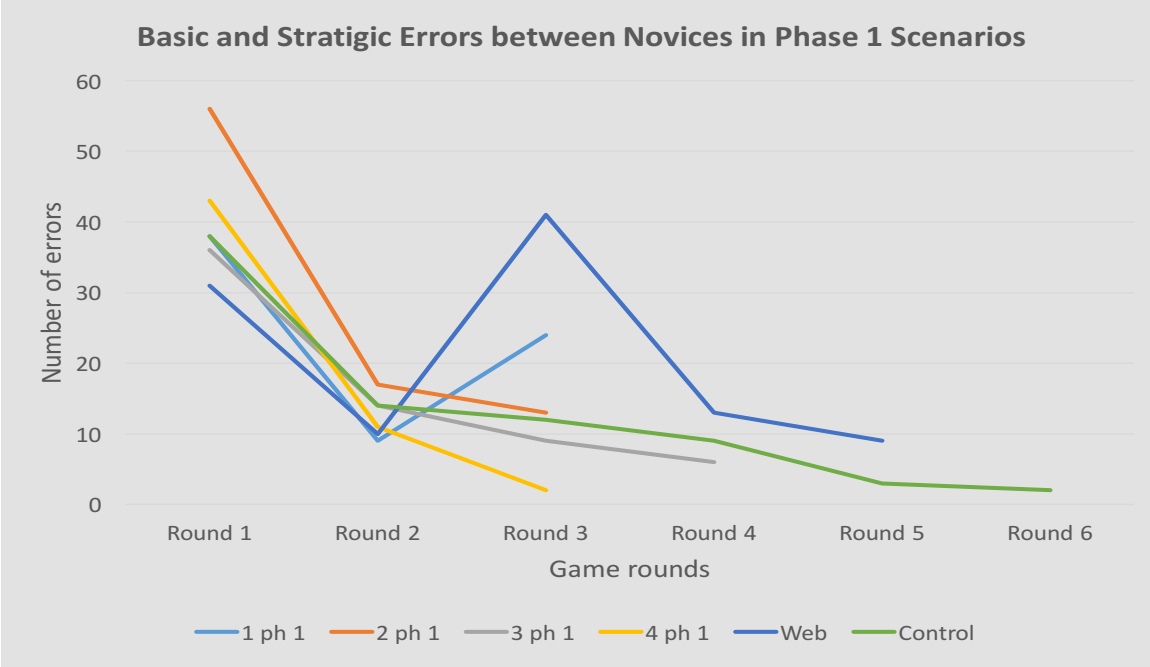


Figure 5.4: Basic and strategic errors committed by novices in phase one scenarios

Presence

Interestingly, novices who felt more present in all scenarios also had higher knowledge gain scores, that is, there was a very strong positive correlation (0.83) between presence and learning outcomes. Moreover, Pearson's correlation also showed moderate positive correlation between learning outcomes and immersion (0.61) as well as engagement (0.60). These

findings support hypotheses 1.i.a on page 94, 1.i.b on page 94 and 1.i.c on page 94.

Additional analysis revealed a statistically significant difference between the PMs in our phase 1 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 as shown in table 5.7 on page 113. These findings support hypothesis 4.i.a on page 96.

Table 5.7: Presence between scenarios - p-adjusted results using Tukey's HSD test

	p-adjusted
2 ph 1-1 ph 1	0.9735371
3 ph 1-1 ph 1	0.8921981
4 ph 1-1 ph 1	0.6066876
control-1 ph 1	0.7221016
web-1 ph 1	0.1076611
3 ph 1-2 ph 1	0.9995241
4 ph 1-2 ph 1	0.9511994
control-2 ph 1	0.3065921
web-2 ph 1	0.3626456
4 ph 1-3 ph 1	0.9932021
control-3 ph 1	0.1868683
web-3 ph 1	0.5363462
control-4 ph 1	0.0692098*
web-4 ph 1	0.8435556
web-control	0.0062452***

* p <0.1
** p <.05
*** p <0.01
**** p <0.001

Immersion and engagement

The ANOVA test was also carried out to test differences in the immersion and engagement levels among the phase one scenarios. A statistically significant difference was found between the MiRTLE+ scenarios, web and control groups ($F(5, 18) = 2.924, p = 0.0419$), supporting hypothesis 4.i.b on page 96 of this study. To follow up the multiple comparisons, the Tukey's

HSD test was applied as presented in table 5.8 on page 114. The result showed that the difference between control and web group was statistically significant at 0.1.

Table 5.8: Immersion between scenarios - p-adjusted results using Tukey's HSD test

	p-adjusted
2 ph 1-1 ph 1	0.9999845
3 ph 1-1 ph 1	0.9999845
4 ph 1-1 ph 1	0.9999354
control-1 ph 1	0.4476167
web-1 ph 1	0.4189143
3 ph 1-2 ph 1	0.9995280
4 ph 1-2 ph 1	0.9990046
control-2 ph 1	0.3643799
web-2 ph 1	0.5073389
4 ph 1-3 ph 1	0.9999999
control-3 ph 1	0.5380802
web-3 ph 1	0.3387124
control-4 ph 1	0.5691923
web-4 ph 1	0.3141911
web-control	0.0140344*

* p <0.1
** p <.05
*** p <0.01
**** p <0.001

A similar analysis was also conducted for the engagement variable. Since no statistically significant difference was determined from ANOVA ($F(5, 18) = 2.31, p > 0.05$), we do not have credible evidence to reject the null hypothesis 4.i.c on page 96.

Interfaces within scenarios of phase one

Presence, immersion and engagement

A deeper analysis was also carried out to reveal the differences between interfaces in our phase one 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, immersion and engagement

variables between those four interfaces by using one-way ANOVA test as presented in the following table 5.9 on page 115 below.

Table 5.9: 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**
Engagement	6.484	(3,20)	0.0412*

* p <.05
** p <0.01

The above table shows statistically significant differences among the interfaces for all three variables. To follow up, we applied the pairwise Tukey's HSD test and found a significant difference of $p < 0.01$ between c and w for the presence and immersion variables, although for engagement, the p-value was 0.05. Further, from the previous table 5.6 on page 111, 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. These findings support hypotheses 3.i.a on page 95. and 3.v.a on page 96. On the other hand, the pairwise comparison test for the immersion and engagement variables showed that the significant difference was only between the c group and the w interface at 0.01 and 0.05, respectively. These findings support hypotheses 3.v.b on page 96 and 3.v.c on page 96. However, since no significant difference was found between other interfaces, the evidence is not adequate to reject the 3.i.b on page 95 and 3.i.c on page 95 null hypotheses.

Teaching experience with other factors

In the present study, teaching experience refers specifically to how experts can evaluate

the interface technology for delivering knowledge to novices. The subsequent analyses were conducted to examine the differences between all scenarios as well as to specifically examine interfaces with the exclusion of the control group as no technology was used by the participants in this group.

Figure 5.5 on page 117 illustrates the differences in the experts' teaching means (TMs) between scenarios. From this we could infer that the MiRTLE+ scenarios (i.e. 1 ph 1, 2 ph 1, 3 ph 1 and 4 ph 1), which involved AR-based and VR-based interfaces, afforded a better teaching experience than the web scenario (3.05 (0.06), 3.55 (0.26), 3.32 (0.06), 2.91 (0.64) and 2.82 (0.26), respectively) as presented in table 5.6 on page 111. However, by excluding scenario 4 (i.e. 4 ph 1), which involved only AR interfaces for experts, one-way ANOVA showed a statistically significant difference at $p < 0.1$ between MiRTEL+ scenarios and the web scenario, indicating that scenarios with mixed AR and VR interfaces yield a better teaching experience than those using web-based platforms. These findings support hypothesis 5.i on page 96. However, as shown above, one scenario with AR interfaces did not show significantly different findings from the web-based interface. Therefore, the null hypothesis for 5.iii on page 96 could not be rejected.

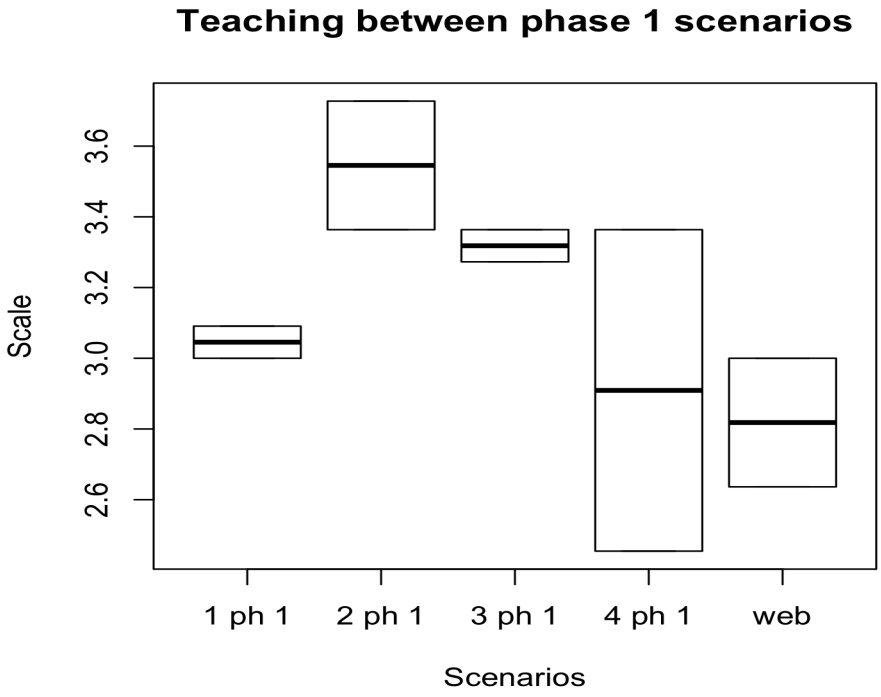


Figure 5.5: Comparing teaching between scenarios

The correlation test was also carried out to identify the effects of experts' experiences toward their sense of presence, immersion and engagement and novices' learning gain scores. Moderately positive correlations in experts' responses with their presence and engagement (0.45 and 0.51, respectively). These findings support our hypotheses 5.v.a on page 96 and 5.v.c on page 96. However, a weak correlation (0.14) was found in experts' immersion, and thus the null hypothesis for 5.v.b on page 96 cannot be rejected. Moreover, the correlation between novices' learning outcomes and experts' experiences was moderately positive (0.53), supporting hypothesis 5.iv on page 96.

5.4 Phase two experiment

As in the case of the previous section, the following table 5.10 on page 118 shows the analysis of phase two scenarios descriptively. This table presents the means of all dependent variables

(i.e. presence, immersion, engagement, learning outcomes and teaching experiences) based on the interfaces used by experts and novices in each scenario. In phase two of the study, immersive interfaces were involved in the MiRTLE+ scenarios (i.e. Meta 1 glasses for local students (AR) and Oculus Rift glasses for remote students (VR)).

Table 5.10: Descriptive statistics for scenario-based interfaces - Phase two

	Scenarios interfaces comparisons															
	Scenario 1			*Scenario 2*				*Scenario 3*			*Scenario 4*				*Web*	*Control*
	r	*lg*	*rg*	*rg*	*r*	*lg*	*l*	*r*	*rg*	*lg*	*r*	*rg*	*l*	*lg*		
Presence	4.44	5.88	5.59	3.59	5.47	5.76	5.65	5.47	4.47	5.24	3.06	4.59	5.00	5.65	4.31	5.88
Immersion	4.02	3.96	4.96	3.60	3.56	4.44	4.16	4.24	3.84	4.56	3.04	3.96	4.00	4.04	3.51	4.24
Engagement	3.14	3.14	3.93	3.07	3.71	3.50	3.79	3.29	3.43	4.21	1.29	3.64	3.64	4.07	3.20	4.12
Learning outcomes	30%	50%	N/A	30%	N/A	70%	N/A	50%	40%	N/A	20%	N/A	60%	N/A	35%	45%
Teaching experience	2.91	N/A	3.36	N/A	3.91	N/A	4.00	3.00	N/A	3.82	N/A	3.18	N/A	3.55	2.82	N/A

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

Learning outcomes and scenarios differences

Similar analyses as those conducted in phase one were conducted for the phase two scenarios. Table 5.10 on page 118 shows the mean differences (in percentage) in learning gain scores between MiRTLE+ scenarios. All MiRTLE+ scenario means (i.e. 40%, 50%, 45% and 40%) were higher than that of the web group (35%). Moreover, the scores of novices using totally immersive interfaces such as those in scenario 2 (50%) were higher than those of the control group (45%). Thus, a scenario using more immersive interfaces could result in better or similar outcomes as those of traditional learning. These findings support hypothesis 1.ii on page 94.

As shown in figure 5.6 on page 119, novices' errors also decreased from round 1 to the final round. However, in scenario 4, a slight increase in errors occurred in round 4 compared to the previous round. As mentioned before in the phase one results, this issue of an increase in the web-based scenario errors in round 3 will be discussed along with other factors in the next chapter.

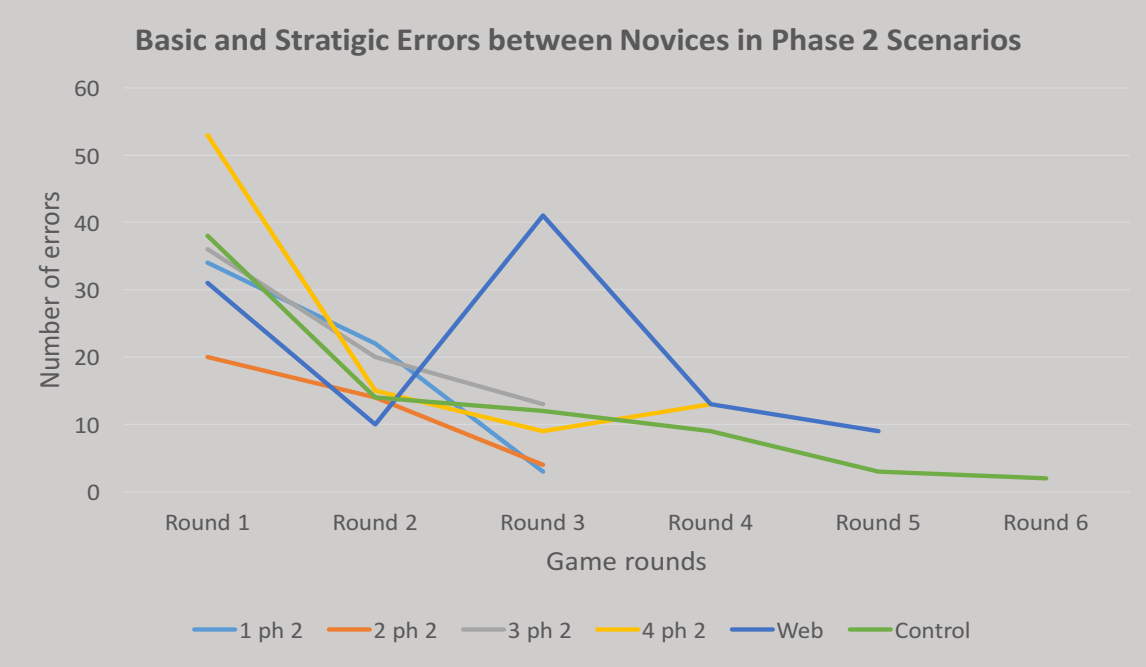


Figure 5.6: Basic and strategic errors committed by novices in phase two scenarios

Presence, immersion and engagement

Differences in the PM, IM and EM between phase two scenarios were also analysed by using one-way ANOVA. The results showed no statistically significant differences between scenarios, although the PMs of all four MiRTLE+ scenarios in phase two suggest that participants seem to feel more present, immersed and engaged within MiRTLE+ scenarios than the web scenario (see the presence box plot in figure 5.7 on page 120). However, there is no credible evidence to support hypotheses 4.ii.a on page 96, 4.ii.b on page 96 and 4.ii.c on page 96.

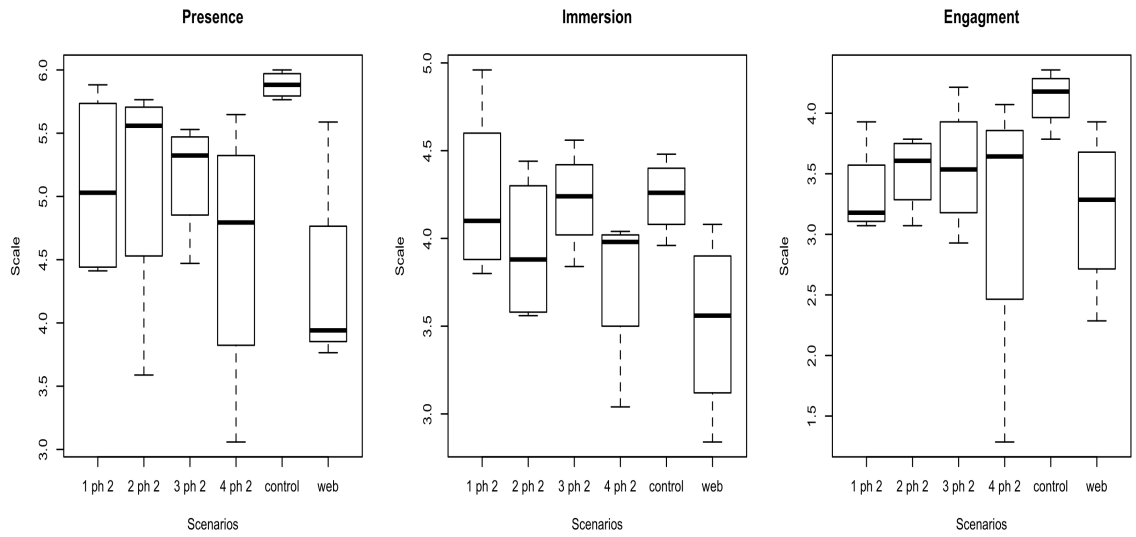


Figure 5.7: Differences between the phase two scenarios of the presence, immersion and engagement

From the previous table 5.10 on page 118, the presence means (with their standard deviations) of the MiRTLE+ scenarios (i.e. 5.09(0.76), 5.12(1.03), 5.16(0.48) and 4.57(1.10)) were very close to those of the control group 5.88(0.11). This result supports premise 4.iii.a on page 96. The immersion levels of the MiRTLE+ phase two scenarios on the same table 5.10 were slightly close to and higher than (in one case) that of the control group: 4.24(0.52), 3.94(0.43), 4.22(0.3), 3.76(0.48) and 4.24(0.22). This supports premise 4.iii.b on page 96. However, the engagement levels varied across the MiRTLE+ scenarios. Only two scenario means (with their standard deviations) 3.43(0.40) and 3.52(0.32) were significantly different from the control group 4.12(0.24). The other two scenarios (i.e. 3 and 4) were not significantly different from the control group. Thus, premise 4.iii.c on page 96 is not supported for all the scenarios. Pearson's coefficient was used to determine the correlation between novices' learning outcomes and presence, immersion and engagement across the phase two scenarios. Moderate positive correlation was observed between presence and learning outcomes (0.40), a clear positive correlation was seen between engagement and learning outcomes (0.64) and a strong positive correlation was seen between immersion and learning outcomes (0.79). This implies that scenarios with more immersive interfaces lead enhanced feelings of immersion.

These correlations support our premises 1.i.a on page 94, 1.i.b on page 94 and 1.i.c on page 94 for phase two.

Interfaces within scenarios of phase two

Analytical tests were also carried out to examine interface differences for the phase two scenarios shown in table 5.10 on page 118. As mentioned, *lg* stands for (AR) local glass interfaces, *rg* denotes remote glass interfaces, *l* stands for (AR) local iPad interfaces, *r* stands for remote users who use VR on screen-based interfaces, *w* is for the web platform users with screen-based interfaces and *c* is for the control group users (i.e. no use of technology).

Presence

A statically significant difference was observed between the presence means for interfaces in phase two, as determined by one-way ANOVA, ($F(5, 18) = 3.114, p = 0.0337$). That was also followed up by applying the Tukey's HSD test as shown in table 5.11 on page 121.

Table 5.11: Immersion between interfaces - p-adjusted results using Tukey's HSD test

	p-adjusted
l-c	0.9422235
lg-c	0.9958727
r-c	0.1781753
rg-c	0.1471994
w-c	0.0589309*
lg-l	0.9957042
r-l	0.9056858
rg-l	0.8178725
w-l	0.5911829
r-lg	0.4041578
rg-lg	0.3250047
w-lg	0.1471994
rg-r	0.9990733
w-r	0.9421437
w-rg	0.9958727

* p <0.1
** p <.05
*** p <0.01
**** p <0.001

The result showed that the statistical difference was between c and w interfaces at 0.1. This supports our hypothesis 3.v on page 96. Further, we realised from the previous table 5.10 on page 118 that the lg interfaces 5.63(0.28), l interfaces 5.32(0.46), rg interfaces 4.56(0.82) and r interfaces 4.73(0.96) showed higher means than the w platform 4.31(0.86). This finding partially supports premise 3.iii.a on page 95 (i.e. only AR-based interfaces were better than web-based platform). We also noted similar values for the lg interfaces and the c group 5.88(0.11), which also partially supports our premise 3.iv.a on page 95.

Immersion and engagement

Analysing the level of immersion in the different interface means shows a statistically significant difference between the lg interfaces and the w interfaces, as determined by a t-test ($t(2.4549) = 4.714, p < 0.1$). Also, the findings suggest that the immersion level of the participants using the lg interfaces 4.25(0.22) is very close to the control group 4.24(0.22), which partially supports premise 3.iv.b on page 95. From the previous table 5.10 on page 118, the immersion means of the other MiRTLE+ phase two interfaces (with standard deviations) rg 4.09(0.60), r 3.85(0.49) and l 4.08(0.11) were slightly higher than the w interfaces 3.51(0.53); however, the evidence was not adequate to reject the null hypothesis of 3.iii.b on page 95. The means (with their standard deviations) of the engagement level for the w interface 3.20(0.69) was higher than that of the r interface 2.98(0.88), whereas the means of the other interfaces (i.e. lg 3.73(0.50), l 3.71(0.10) and rg 3.52(0.36)) were still closer to that of the c group 4.12(0.24) than the w group. Thus, we cannot reject the null hypotheses of 3.iii.c on page 95 and 3.iv.c on page 95.

Teaching experience with other factors

Figure 5.8 on page 123 shows box plots of the mean differences for the phase two scenarios. A significant difference at the $p < 0.1$ level was observed between the scenario two (i.e. 2 ph 2) mean with only VR-based PC interfaces 3.95(0.06) and the web scenario mean 2.82(0.26) as presented in the previous table 5.10 on page 118. This partially supports the premise 5.i

on page 96. On the other hand, the means of the immersive teaching experience in scenario *4 ph 2*, where experts used AR-based and VR-based glasses interfaces, was not significantly different from the web scenario. Thus, the null hypothesis of 5.ii on page 96 cannot be rejected.

Further analysis was conducted to investigate the differences in teaching experience between interfaces in the MiRTLE+ phase two. Using an unpaired t-test between the web-based interfaces and other interfaces, we found that a statistical significant difference at the $p < 0.1$ level between AR-based glass interfaces and web-based interfaces. This result supports the premise 5.vi on page 97

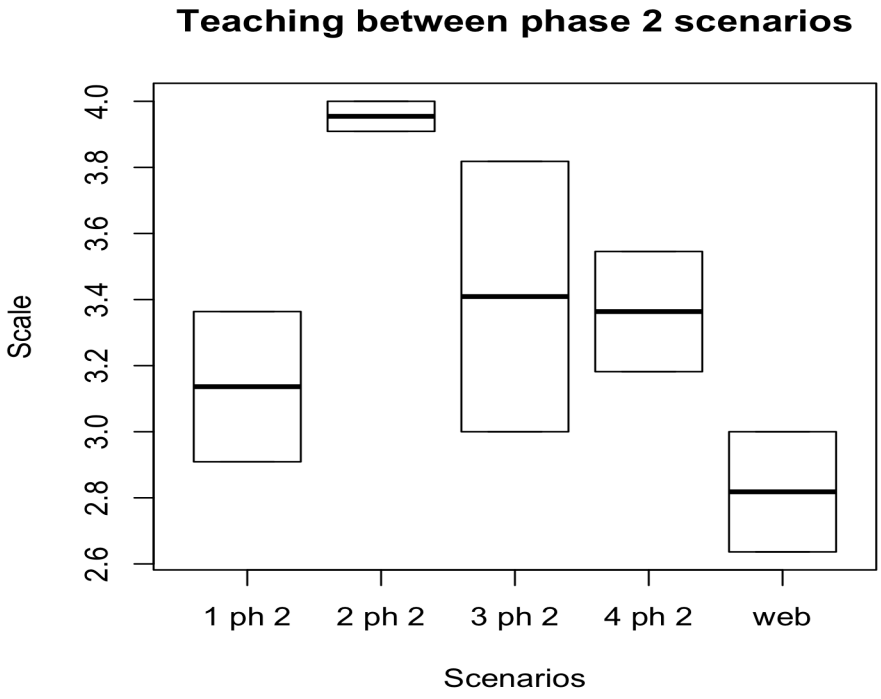


Figure 5.8: Measuring engagement between groups.

We also explored the correlation between the teaching experience factor and learning outcomes in phase two. The Pearson's test showed a strong positive correlation (0.96) between experts' teaching experience and their novices' learning gain scores. This supports our hypothesis 5.iv on page 96. A strong positive correlation was also observed between teaching

experience and presence (0.88) and teaching experience and engagement (0.76). These values support premises 5.v.a on page 96 and 5.v.c on page 96. Because the immersion and teaching experience did not show a strong relationship, the null hypothesis of 5.v.b on page 96 cannot be rejected.

5.5 Overall groups comparison

5.5.1 Learning effectiveness

We examined the means of the learning outcome gains of all novices between groups (regardless of their scenarios). As expected, the control group novices had the highest learning effectiveness score (45%) whereas the web group had the lowest percentage (35%). Moreover, MiRTLE+ in both phase one (41.25%) and phase two (43.75%) had higher learning effectiveness than the web group (35%) and was also close to the control group (45%), as shown in figure 5.9 on page 125. However, we could not reject the null hypothesis of 2.iii on page 95.

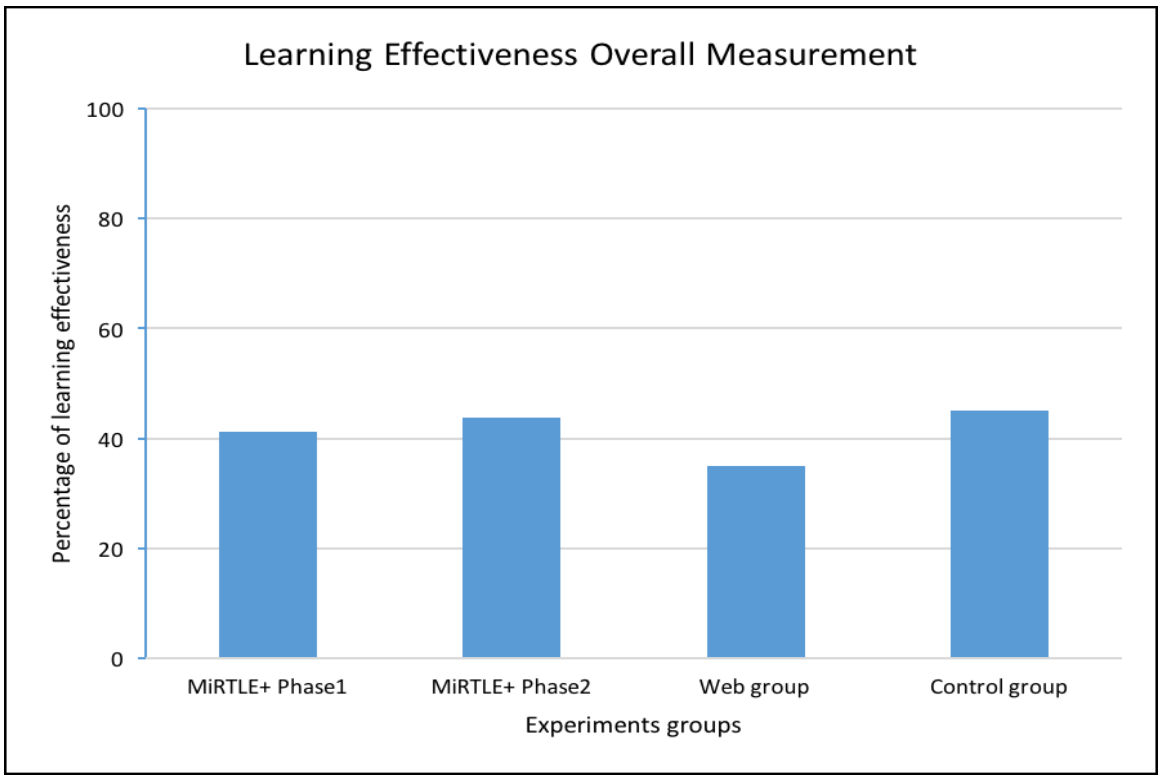


Figure 5.9: Learning effectiveness differences between groups for novices

A closer look at novices' learning improvement data through our error-based system for MiRTLE+ experiments, web group and control group showed that novices' improved their skills by reducing the number of errors from one round to the next round, though this was not the case with the web group (Figure 5.10 on page 126). On inspecting this data, we found that the first two rounds in the web group did not provide sufficient learning gains to equip novices to face more challenges, and therefore, errors increased in round three. We also noted that with the web group, novices and experts had more time for discussions after round 3, indicating that novices had encountered more cases that required checking and discussion. This indication of improvements supports our premise 1.iii on page 95.

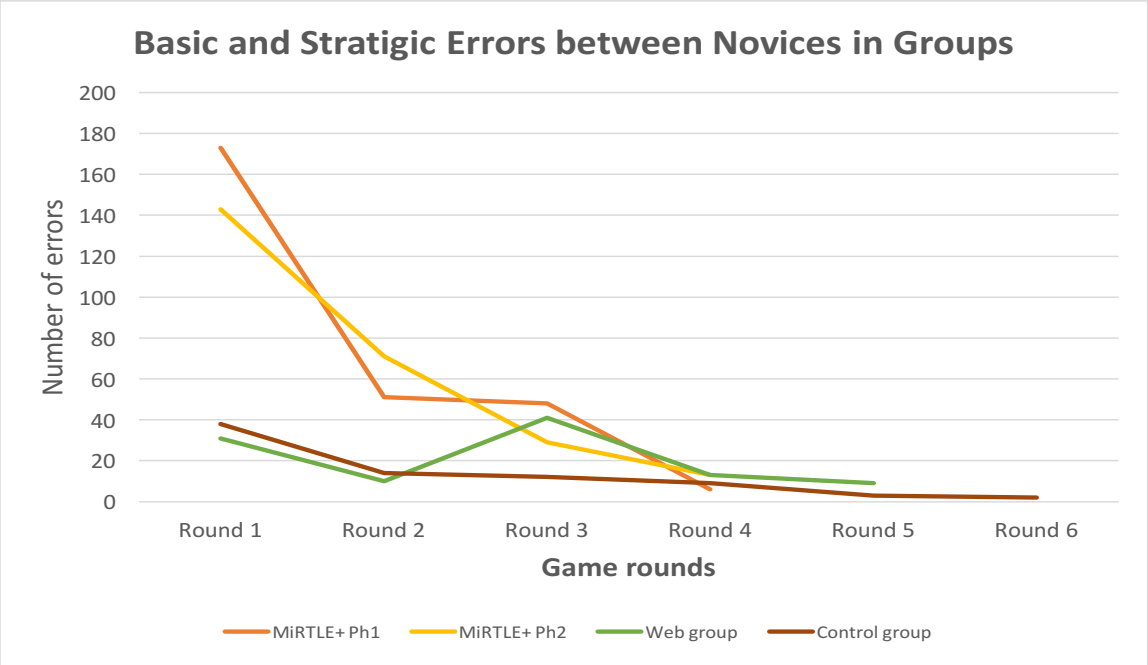


Figure 5.10: Basic and strategic errors of novices between groups

5.5.2 Presence

Figure 5.11 on page 127 illustrates the PMs differences between the experiment groups. From the box-and-whisker plot (commonly called a box plot), one can infer a prominent difference in the PMs median between the control group and the web group and between the two experimental phases and the web group. However, only a small difference seems to exist between the control group within the two experimental phases as well as between the experimental groups themselves.

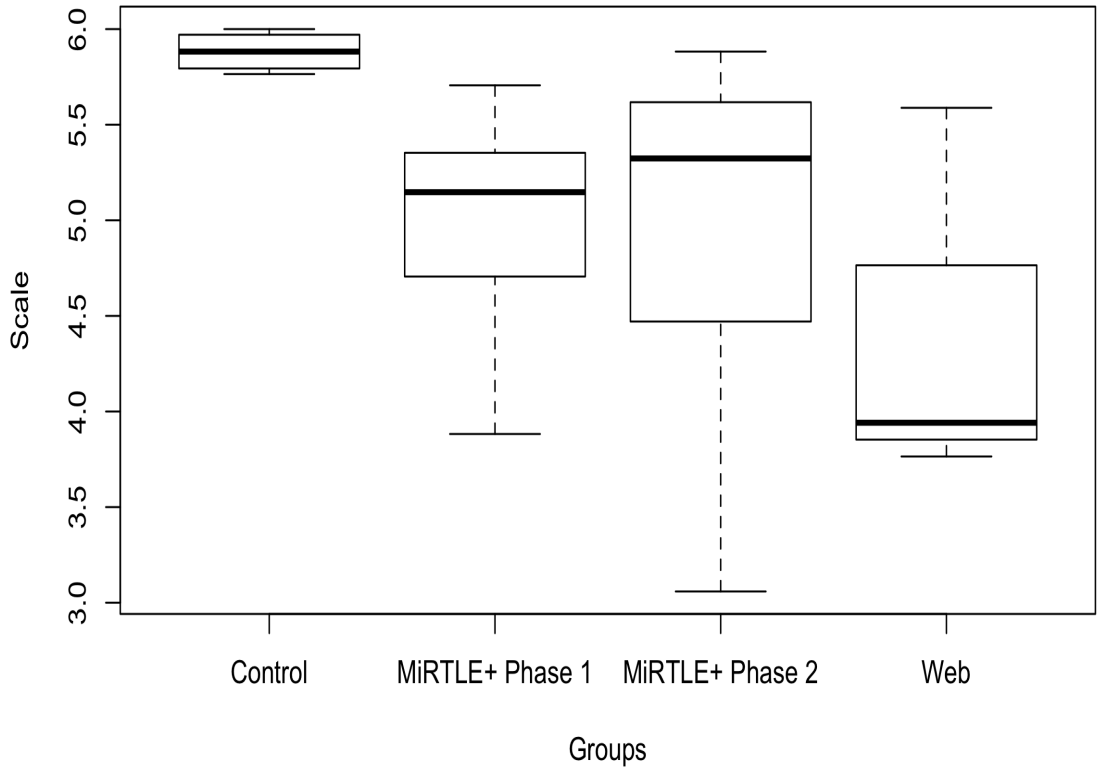


Figure 5.11: Measuring presence between groups

Statistical analyses has showed that the PM means for the experimental groups phase one 5.03(0.49) and phase two 4.99(0.82) were higher than that for the web group 4.31(0.86) and less than that for the control group 5.88(0.11) with their corresponding standard deviations. A statistically significant difference between the groups was determined by one-way ANOVA ($F(3, 36) = 3.774, p = 0.0188$). As a follow-up to the ANOVA, a post-hoc test was conducted (Tukey's honest significant difference (HSD)) to make a pairwise comparison as presented in table 5.12 on page 128. The results showed that the difference between the control and web group was statistically significant at 0.05, whereas the difference between the control and both experimental groups was not statistically significant ($p > 0.5$). Considering the standard deviations, the PMs values of the experimental groups seemed closer to the control group than the web group. These findings support hypotheses 2.i.a on page 95 and 2.ii.a on

page 95.

Table 5.12: Presence p-adjusted results using Tukey's HSD test

	p-adjusted
Control - Phase 1	0.1213088
Control - Phase 2	0.0931691*
Control - Web	0.0100477**
Phase 1 - Phase 2	0.9969821
Phase 1 - Web	0.2274529
Phase 2 - Web	0.2819103

* p <.1
** p <.05

5.5.3 Immersion

To examine the differences in immersion levels between the groups, we plotted the IMs differences using a box plot (Figure 5.12 on page 129). The results showed that MiRTLE+ phase one (3.89(0.16)) and MiRTLE+ phase two (4.04(0.45)) groups had higher immersion levels than the web group (3.51(0.53)) and were also closer to the control group (4.24(0.22)).

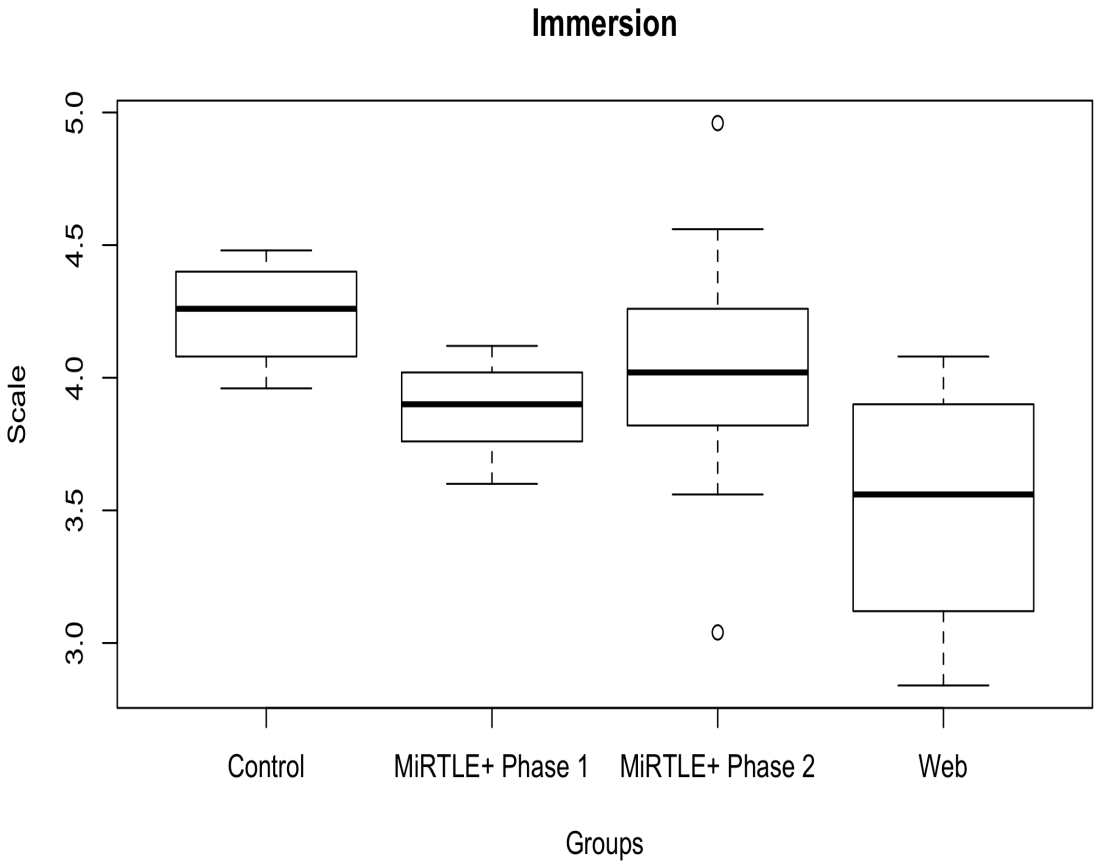


Figure 5.12: Measuring immersion between groups

A statistically significant difference between groups was determined by one-way ANOVA ($F(3, 36) = 3.629, p = 0.0219$), and as a follow-up to the ANOVA results, Tukey's HSD test was used. The results are shown in table 5.13 on page 129.

Table 5.13: Immersion p-adjusted results using Tukey's HSD test

	p-adjusted
Control - Phase 1	0.2837557
Control - Phase 2	0.7294785
Control - Web	0.0246540*
Phase 1 - Phase 2	0.6129511
Phase 1 - Web	0.2185402
Phase 2 - Web	0.0442440*

* p <.05

The HSD test showed a statistically significant difference between the control and the web groups at $p > 0.05$ and between the phase two group and the web group at $p > 0.05$. However, differences between the experimental groups and the control group were not significant. This suggests that our experimental groups enjoyed a higher immersion level than the web group and that the immersion level of the experimental groups, especially in phase two, was closer to that of the control group, which supports our premise 2.i.b on page 95 and 2.ii.b on page 95.

5.5.4 Engagement

As shown in figure 5.13 on page 131, the groups showed different levels of engagement. The EMs of the control group was the highest 4.12(0.24), whereas that of the web group was the lowest 3.2(0.69). However, the EMs of the experimental groups in phase one and phase two was better than that of the web group (3.83(0.39)) but less than that of the control group (3.39(0.68)).

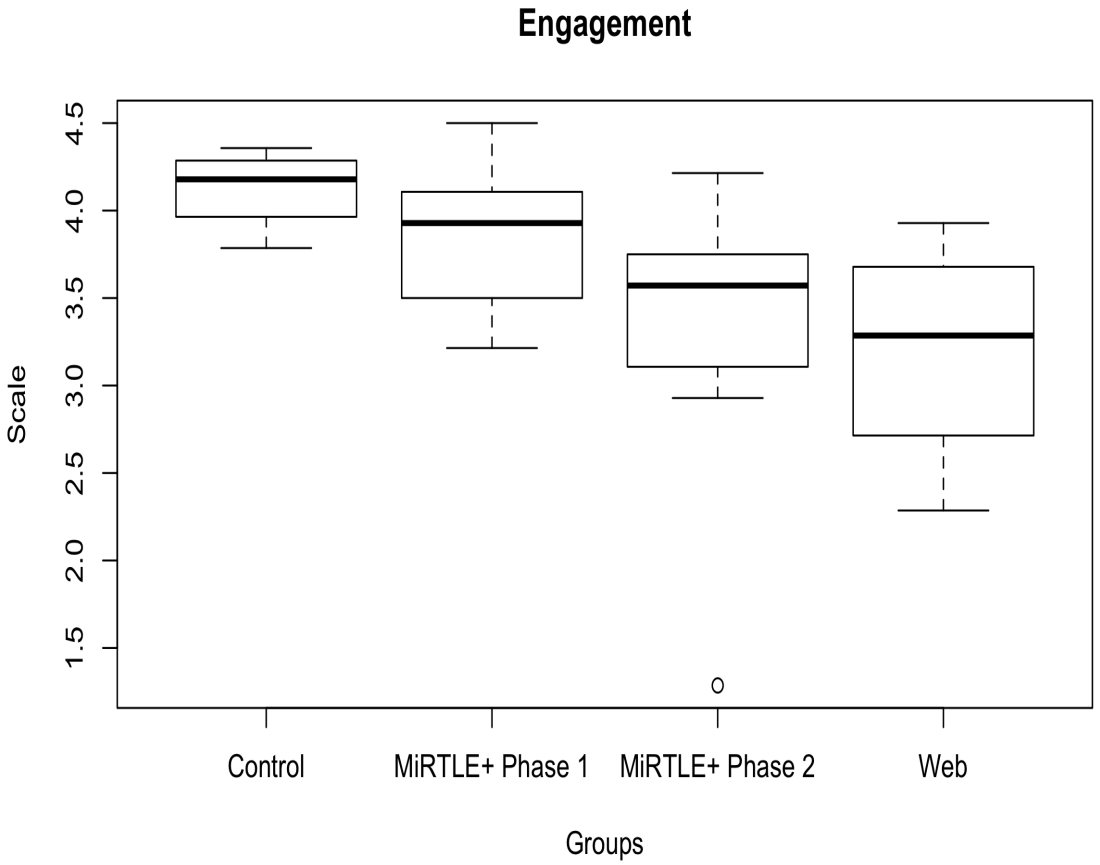


Figure 5.13: Measuring engagement between groups

A one-way ANOVA test showed a statistically significant difference in the EM data between our groups ($F(3, 36) = 3.696, p < 0.05$). Therefore, we concluded that only the overall significant difference, based on the ANOVA test, supports our hypothesis 2.i.c on page 95. However, we obtained no credible evidence from the pairwise comparison test to support hypothesis 2.ii.c on page 95.

5.6 User experience

We employed the user experience questionnaire (UEQ) to obtain user feedback on our systems. The UEQ includes 26 items that are rated on a seven-point semantic differential scale.

The items are distributed to measure six scales: attractiveness; perspicuity; efficiency; dependability; stimulation; and novelty (Table 5.14 on page 132). Compared to other end-user system surveys, the UEQ enables quick assessment and the efficient collection of user feedback, impressions and attitudes about the system under investigation. Moreover, the UEQ has been validated on different products; it shows high reliability for all the scales with the exclusion of dependability [155].

Table 5.14: Scales descriptions [203]

Scale	Description
Attractiveness	Overall impression of the product. Do users like or dislike the product?
Perspicuity	Is it easy to get familiar with the product? Is it easy to learn how to use the product?
Efficiency	Can users solve their tasks without unnecessary effort?
Dependability	Does the user feel in control of the interaction?
Stimulation	Is it exciting and motivating to use the product?
Novelty	Is the product innovative and creative? Does the product grab the interest of users?

5.6.1 Reliability

After collecting data, the results of the UEQ shows a high reliability for only three factors: attractiveness, stimulation and novelty that is $\alpha > 0.7$.

Table 5.15: Cronbach's alpha results for the UEQ scales

	Cronbach's Alpha
Attractiveness	0.91
Perspicuity	0.64
Efficiency	0.69
Dependability	0.64
Stimulation	0.87
Novelty	0.71

5.6.2 Comparison of MiRTLE+ scenarios with the web scenario

The differences in p-values, as determined by a t-test, for each MiRTLE+ scenario and the web scenario are presented in table 5.16 on page 133. The results show a significant difference in the novelty factor between the web scenario and some of the MiRTLE+ scenarios. Moreover, within the novelty factor, the least difference between the scenarios was observed for scenario 4 in phase two. This supports our phase two finding with regards to low levels of presence, engagement and immersion specifically in scenario 4. However, the null hypothesis 7.i on page 97 could not be rejected for all scenarios and factors. Therefore, we analysed the differences between the web interface and the AR and VR interfaces.

Table 5.16: Scenario-based comparison with the web group - *t-test*

Scenario	*Web scenario* ***(p-value)***					
	Attractiveness	*Perspicuity*	*Efficiency*	*Dependability*	*Stimulation*	*Novelty*
S1-Ph1	0.3818	0.4091	0.1861	0.1369	0.1269	0.0029***
S2-Ph1	0.3099	0.6900	0.6210	0.4866	0.1991	0.0679*
S3-Ph1	0.3364	0.3084	0.1272	0.3080	0.2155	0.1873
S4-Ph1	0.4436	0.7643	0.5411	0.8925	0.3451	0.1492
S1-Ph2	0.6470	0.8051	0.3073	0.8689	0.1843	0.0483*
S2-Ph2	0.6394	0.3925	0.3061	0.4639	0.2798	0.0624*
S3-Ph2	0.2914	0.5835	0.1808	0.5101	0.1843	0.0058***
S4-Ph2	0.3066	0.7089	0.9117	0.8483	0.8061	0.6827

* p <0.1
** p <0.05
*** p <0.01

We found significant differences between the web interface and other interfaces with the exclusion of VR PC screen interfaces. This supports hypothesis 7.ii on page 97 and 7.iii on page 97 on the novelty factor only.

Table 5.17: Interfaces-based comparison with the web group - *t-test*

Interface	*Web interface* ***(p-value)***					
	Attractiveness	*Perspicuity*	*Efficiency*	*Dependability*	*Stimulation*	*Novelty*
r (remote - pc screen)	0.5237	0.7200	0.2994	0.7811	0.1581	0.3075
l (local - iPad)	0.4567	0.7433	0.4297	0.5045	0.2164	0.0111**
lg (local - glasses)	0.4677	0.4197	0.2041	0.4438	0.2617	0.0110**
rg (remote - glasses)	0.9329	0.7112	0.6018	0.8200	0.4087	0.0997*

* p <0.1
** p <0.05
*** p <0.01

Overall, the user experience results of the MiRTLE+ systems and the web platform were compared with a benchmark dataset extracted from 163 studies on different products (business software, web pages, web shops, social networks, etc.). Figure 5.14 on page 135 shows the mean of user experiences as a black line. The figure shows that our phase one system received a higher evaluation from users on all the factors (i.e. attractiveness, perspicuity, efficiency, dependability, simulation and novelty) than the benchmark dataset values. Figure 5.15 on page 135 shows that the user experience in our phase two system was rated as high on four factors. However, compared to the benchmark values, the dependability factor was above average, and the novelty factor was less than excellent. This supports our hypothesis 7.v. On the other hand, the web system received a poorer evaluation than our MiRTLE+ systems on user experience, especially on the novelty factor (Figure 5.16 on page 136).

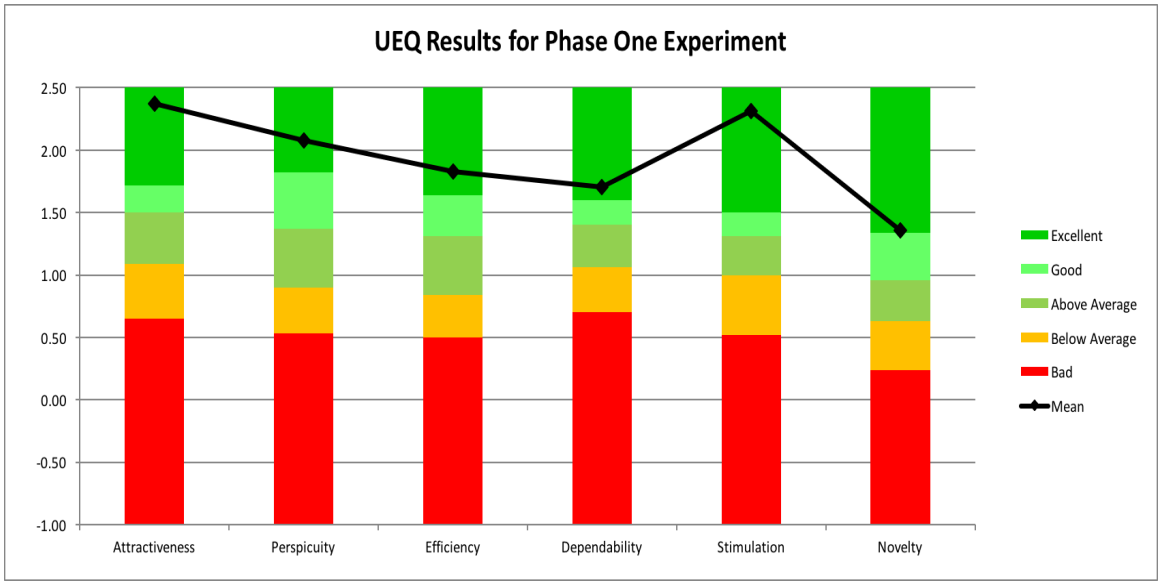


Figure 5.14: MiRTLE+ system - phase one

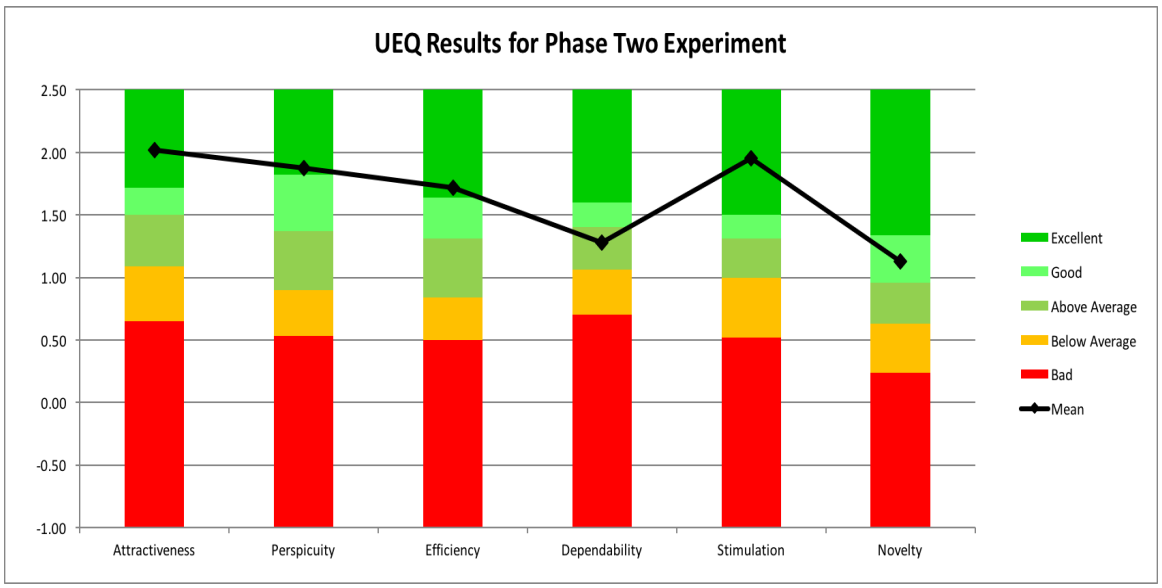


Figure 5.15: MiRTLE+ system - phase two

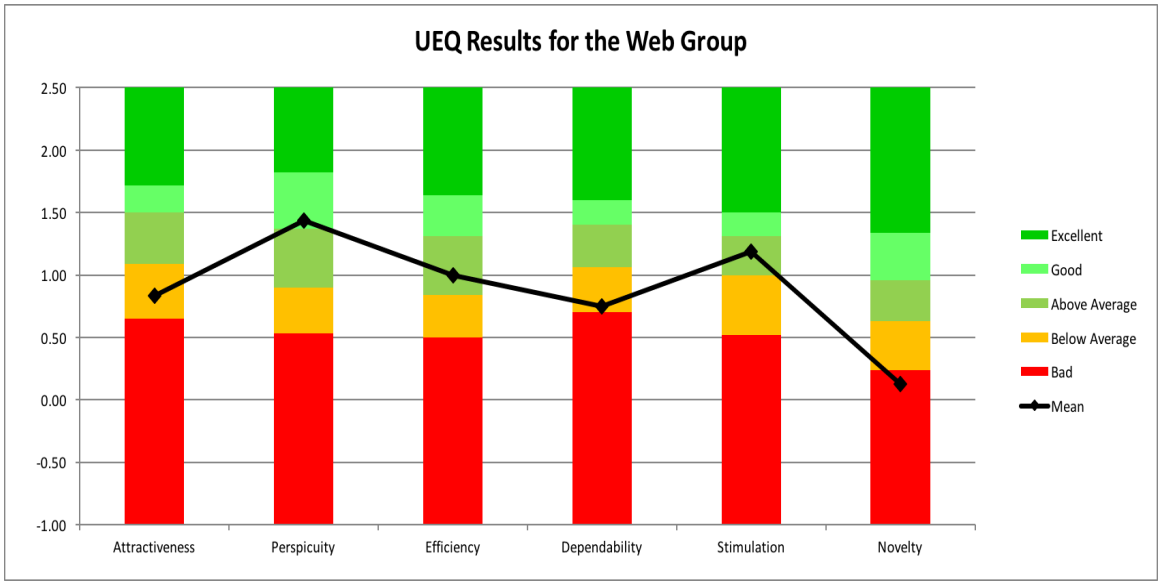


Figure 5.16: Web system

5.7 Summary

This chapter presented the results of our experiment results. Section one explained the demographic and technical characteristics of our sample, in addition to the data collected and the types of quantitative and qualitative measurements undertaken. In section two, we presented the reliability measures (Cronbach's alpha coefficients) for all our study variables. Sections three and four reported the results of the phase one and phase two experiments, respectively. These results were ordered based on the dependent variables from learning effectiveness, presence, immersion, engagement to teaching experience. Section five presented the results for the study variables analysed. Lastly, the user experience findings for each independent variable were described for both the phases. In the next chapter, we discuss these results to answer the research questions.

Chapter 6

Discussion

The previous chapter presented the results of the analysis of the MiRTLE+ platform experiments. In this chapter, we discuss our results with a view to answer the research questions. We first discuss the results of phase one followed by phase two, and then compare the results of the experiment groups in the later section. Thus, our main research questions as detailed in Chapter 1, section 1.4 on page 5 are divided into sub-questions based on our dependent variables (i.e. learning and teaching effectiveness, psychological factors (presence, immersion and engagement), and user experience) as shown in figure 6.1 on page 138 and then discussed in details in this chapter. The chapter ends with a summary of these discussions.

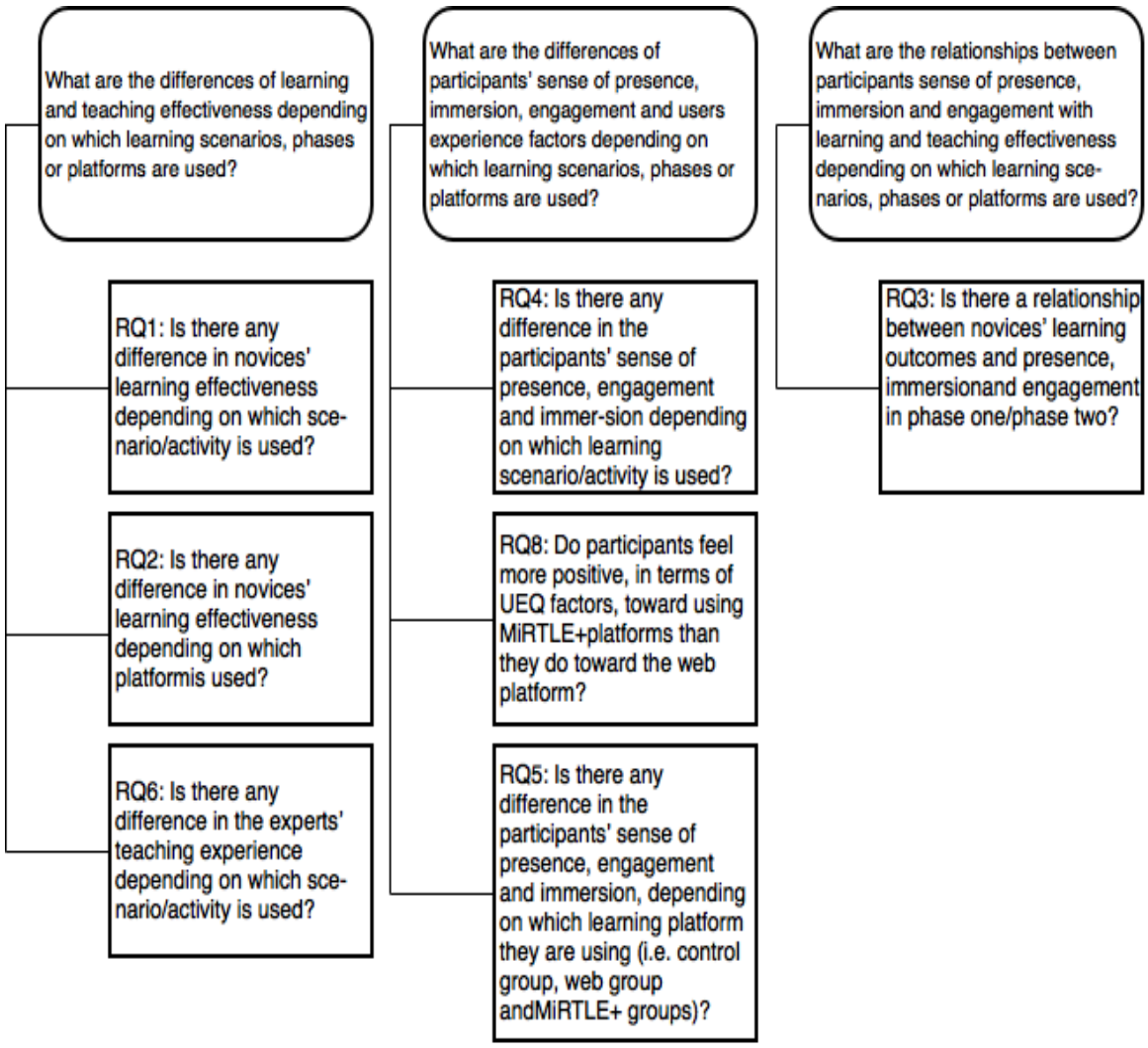


Figure 6.1: Detailed research questions

6.1 Phase one

RQ1: Is there any difference in novices' learning effectiveness depending on which scenario/activity is used?

Learning

In our phase one 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 those of previous studies [204, 205].

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 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. [85] 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.

Another remarkable point related to the learning gain scores is that one of the scenario 1 novices showed a very low score (10%) compared to the average gain scores (42%). By inspecting the record of this participant, we learned that they had no previous knowledge of playing card games which may have caused this. Moreover, the low score also confirmed

that this participant's progress based on their error frequency was still high compared to the other novices' progress.

RQ3: Is there a relationship between novices' learning outcomes and presence, immersion and engagement in phase one/phase two?

RQ4: Is there any difference in the participants' sense of presence, engagement and immersion depending on which learning scenario/activity is used?

Presence

Our results demonstrate that participants felt spatially present in all MiRTLE+ scenarios in phase one (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 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 [206]. 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" [207]. Witmer and Singer echoed this same sentiment saying, "it would be very surprising indeed if positive relationships between presence and performance were not found" [110].

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 [84, 83]. 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. By comparing the immersion levels of the MiRTLE+ scenarios with our baseline control group, we found that holding an iPad or focusing on the mouse and keyboard controls to look around for your partner and showing/hiding the game cards could result in a decrease in the immersion levels (although not significantly). A moderately positive association was observed between immersion and learning outcomes.

Engagement

Differences in the means of the engagement levels were observed between the MiRTLE+ scenarios and the web-based and control groups as well as within the MiRTLE+ scenarios themselves. The engagement mean was the highest for the control group and lowest for the web platform. However, these differences were not significant. If engagement is defined as the first fully immersed stage [117], then this insignificant difference is reasonable when

comparing groups in different learning scenarios with similar learning tasks. Moreover, Appel [208] reported that communication and interaction in 3D virtual spaces do not replace face-to-face conversation; rather they enable instructors and learners to work with one another across distances.

In contrast, when considering the interfaces in the absence of the learning scenarios, the control group users, VR users, and AR users showed significantly different levels of engagement from the web users. This result supports the explanation that 3D virtual environments, which are engaging and interactive for learning, may not be provided by Web 2.0 platforms [160]. With regard to learning effectiveness, the correlation between learning outcomes and engagement was moderately positive, which also supports the view that 'engagement in the game has a clear positive effect on learning' [85].

RQ6: Is there any difference in the experts' teaching experience depending on which scenario/activity is used?

Teaching

We carried out further investigation in this study focusing more on the experts' experiences within each scenario and technology being used. This revealed that experts exposed to a mix of VR and AR scenarios or only to VR scenarios had significantly more positive responses than those exposed to the web scenario. In contrast, with only the AR scenario, experts' positive responses were not significantly different from those of the web users, even though their means were higher. Perhaps, experts may have felt distracted holding the iPads while also choosing avatars and discussing the rules. The following expert comment on using an iPad is indicative of this:

"I really enjoyed playing the game as an expert. However, I didn't find that augmented reality was necessary in the game"

RQ8: Do participants feel more positive, in terms of UEQ factors, toward using MiRTLE+ platforms than they do toward the web platform?

User experience

The t-test analysis revealed a significant difference only in terms of novelty between the web scenario and the first two scenarios in phase one. By analysing the participants' technical knowledge of augmented reality, mixed-reality, 3D spaces and immersive glasses, we found that the majority of these participants belonged to only these two scenarios (i.e. 1 and 2) in phase one. In other words, given that significant differences were only associated with novelty, which reflects the users' interests as well as our system's innovation, it is likely that users who are not interested in new technology may perceive no difference between this and web technology. However, on comparing our phase one system with other products benchmarked by the UEQ tool, we found that our system scored very well on all factors of the UEQ. This suggests that our phase one system involving the development of AR-based iPads and VR-based PC screens was attractive, stimulating and novel.

6.2 Phase two

RQ1: Is there any difference in novices' learning effectiveness depending on which scenario/activity is used?

Learning

The results of the phase two experiments demonstrate that the novices in the MiRTLE+ scenarios learned better than novices in the web scenario. Furthermore, the immersive scenarios (i.e. use of VR and AR glasses for both remote and local novices) also revealed better learning than in the control group scenario. However, on inspecting the novice interfaces individually for the separate AR glasses and immersive VR scenarios, we found that the learning outcomes were less effective for the VR glasses. On the basis of the evidence currently available, it seems plausible to suggest that learning was increased by only the AR glasses. Perhaps, one of the main issues influencing the learning outcomes and other factors, as we will discuss later in this section, are the problems associated with the VR glasses.

Davis et al. [209] explained that VR and its equipment such as Oculus Rift are known to induce cybersickness. A novice in our experiment using the immersive VR glasses felt that the glasses were 'not quite comfortable'. However, the experience of cybersickness varies across individuals and technologies [210]. Thus, we infer that one of the reasons for the varied responses to the VR glasses could be cybersickness. With regard to the novices' learning improvement in our error-based system, the number of errors decreased dramatically from one round to the next. However, as discussed before in the web scenario, as well as in the scenario 4 of phase one, both had an increase in errors in round 3 and a slight increase in errors during scenario 4 in round 4 in phase two. It is likely that the increase in errors in round 4 in scenario 4 perhaps occurred because the playing time was longer and the discussion time was shorter. However, the overall improvement compared to the first round was still notable.

Elapsed times in the game rounds in phase two were longer than in phase one for some scenarios. While this could be attributed to the change in the players cards from round to round, these findings also support the results of studies that found that users using HMD devices spent more time than those who used desktop interfaces [211, 73].

RQ3: Is there a relationship between novices' learning outcomes and presence, immersion and engagement in phase one/phase two?

RQ4: Is there any difference in the participants' sense of presence, engagement and immersion depending on which learning scenario/activity is used?

Presence

The presence level means varied between MiRTLE+ scenarios, and the web and control scenarios, with the control group showing the highest level of presence and the web group showing the lowest. However, this difference was not statistically significant. The decrease in presence levels was most noticeable in the case of the VR glasses and for one case of a VR PC screen interface. We may deduce that effects similar to cybersickness (that was mentioned previously for learning outcomes) induced by the VR glasses interfaces could possible lead

to a reduction in the presence levels for both novices and experts. A deeper analysis of the presence means between participants' interfaces showed that the AR glasses and the control group had significantly higher scores than the web group. In addition, the AR glasses means were very close to that of the control group. Overall, we attribute the decrease in presence in some scenarios to the problems associated with VR glasses (i.e. their side effects) and the low quality of the PC screen interfaces.

A moderate positive correlation was observed between presence and novices' learning gain scores. On the other hand, a strong positive correlation was noted between presence and teaching experience. As discussed before in phase one, these findings support the existing knowledge that learning and teaching are considerably associated positively with the users levels presence.

Immersion

At the immersion level, the means of the MiRTLE+ scenarios results were highly convergent with the control group means. Further investigation of the interfaces revealed that the means of the AR glasses as well as the control group were significantly different from those of the web interfaces. This suggests that the AR devices using glasses considerably increased the level of immersion to more closely mimic reality. Immersion was strongly positively correlated with the novices' learning outcomes, whereas no correlation was observed between immersion and the teaching experiences. The lack of an association could be because experts may not have the same concerns as novices about learning new rules in these tasks, and thus experts may spend their time discovering and thinking about using this technology rather than being immersing in the learning task itself. This aligns with one of qualitative outcomes of a previous study [212] where some participants who were not in a learning mode focused on the opportunities that the new technology afforded. On the other hand, the analysis of the immersion levels did not reveal a remarkable difference between the MiRTLE+ scenarios and the web or control scenarios. This was possibly due to the other interface effects that led to a decrease in immersion levels, such as cybersickness induced by the VR glasses or the

lack of user knowledge of some of these technologies, which may have caused participants to focus on the functions of the interfaces or applications rather than on the learning task itself.

Engagement

The engagement levels were not affected by the different settings of the learning scenarios. This may be due to reasons similar to those suggested for the immersion levels which may also be applicable to engagement. Moreover, it is likely that by its very nature, a game-based learning task engages both novices and experts in all scenarios and thus helps them become more engaged in learning and using rules via collaboration [213]. A separate study reported several cases of participants who were so engaged with the game-based environment that they lost track of their surroundings [214]. This may explain why the levels of engagement might not be different between the MiRTLE+ scenarios and other control scenarios. Further, the engagement level has a strong positive correlation with the novices' learning outcomes, which supports findings of Hamari et al. [85], who found that engagement has a clear positive association with learning effectiveness within a game-based context. Also, a strong positive correlation was observed between feedback on the teaching experiences and engagement. According to this finding, experts who were more engaged with their technology interfaces tended to support the use of their interfaces. A sense of challenge between the participants supports the finding in the literature that a game-based environment mimics actual games and thus leads to a greater sense of engagement for players (e.g. [215], [216] and [217]).

RQ6: Is there any difference in the experts' teaching experience depending on which scenario/activity is used?

Teaching

With regard to the experts, the findings were not significantly different between the more immersive MiRTLE+ scenarios, where both or either expert wore glasses, and the web scenario, though the means from the MiRTLE+ scenario were higher. However, experts in a scenario similar to phase one (i.e. using iPad and PC screen) showed significantly different

results from those in a web scenario, which supports the the phase one findings for the experts' feedback on the scenarios. Further, their positive feedback towards the technology interfaces (AR-based glasses and web-based interfaces) varied significantly. Such prominent differences were not observed between the web-based and other interfaces. We infer from these findings that the more immersive interfaces with the problems of VR glasses may have detracted the experts from using this interface. Plausibly, these issues did not occur within the learning scenarios that did not use the VR glasses.

RQ8: Do participants feel more positive, in terms of UEQ factors, toward using MiRTLE+ platforms than they do toward the web platform?

User experience

In this study, we mainly consider the high reliability factors of the UEQ: attractiveness, stimulation and novelty. Similar to phase one, a significant difference was noticed between the web-based scenario and the 3 scenarios of phase two with regard to the novelty factor. The same reason as in phase one could be applied: the majority of the participants who were familiar with these new technical interfaces belonged to the first 3 scenarios. Therefore, they may have been more interested in the technology, which may have positively influenced their evaluation of the creativity and innovation (i.e. the novelty factors) of the phase two system. Moreover, the UEQ findings of scenario 4, in terms of the novelty factor, also supports our findings related to the presence, immersion and engagement factors. As presented in the results chapter, figure 5.7 on page 120, some users from scenario 4 who were not interested, also recorded low level means in the presence, immersion and engagement factors.

Overall, the phase two system showed a high level of attractiveness, stimulation and novelty as against the UEQ benchmarks. Although our dependability score was not highly reliable (0.7), it was less than that of the phase one system. This supports our discussion on the low levels of presence, immersion and engagement in some scenarios: where some participants did not feel in control of the interaction because of their use of the interfaces, where they had difficulty with the unstable hand gestures, AR glasses, and cybersickness associated with

the VR glasses, or had distractions from looking around, or showing/hiding the game board while doing the game tasks.

A closer study of the interfaces revealed significant differences between the web-based interface and AR-based interfaces and between the web-based and the VR-based interfaces. No significant difference was observed between the web-based interface and VR-based PC screens. This to some extent supports our following claim on the immersive interfaces: where participants did not show a great difference in interest, creativity or innovation between the 3D virtual environment and the web-based interfaces, whereas the difference was prominent with the immersive interfaces.

6.3 Comparison of groups

RQ2: Is there any difference in novices' learning effectiveness depending on which platform is used?

With regard to the learning outcomes of MiRTLE+, after conducting a statistical analysis on the pre- and post-test scores, we found that novices who collaborated within the MiRTLE+ platforms either in phase one (who used AR and VR interfaces) or phase two (i.e. who used more immersed wearable AR and VR interfaces) performed better on knowledge gains than those who were instructed on the web-based platform. The MiRTLE+ novices were also closer in achievement to the traditional collaborative group learning. However, the difference of learning outcomes between these groups was not statistically significant. On the other hand, all novices showed improvement by decreasing their errors and by observing their errors decreasing. We believe that phase one and phase two share similarities. Owing to limited equipment for the trials, where we had only one pair of VR and one pair of AR glasses each, this meant 50% of each scenario in phase two was similar to the scenarios in phase one in which the participants used handheld and screen-based devices.

RQ5: Is there any difference in the participants' sense of presence, engagement and immer-

sion, depending on which learning platform they are using (i.e. control group, web group and MiRTLE+ groups)?

Our results showed a significant difference between all groups in presence levels. That is, the presence level was the highest for the control group and the lowest for the web group. The presence levels of the experimental groups (i.e. MiRTLE+ phase one and phase two) were closer to the control group than to the web group. This is possibly because mixed-reality interfaces have more potential to mimic reality for working in collaborative learning groups. The finding on the immersion levels were similar to those of the presence levels. The control group as well as the phase two groups (i.e. participants using more immersive glasses in their learning scenarios) showed statistically significant different levels of immersion from the web group. However, the levels of the phase one groups (i.e. participants only used iPads and PC screen) were not significant for either groups, and were even slightly closer to the web group. Our claim that AR-based and VR-based interfaces would result in greater immersion is not supported as other problems seem to have played a key role in decreasing the levels of immersion, such as the users' distraction while using iPads. Furthermore, the results showed a significant difference in engagement levels between groups. However, the engagement means and standard deviations of our phase two groups were closer to that of the web group. As discussed above, aspects such as the use of VR glasses may have adversely affected the engagement levels of some users. Some theories point to a strong relationship between immersion and engagement, and because our engagement and immersion levels in some learning scenarios involving technological interfaces were low and convergent, it is likely that this affected those participants who were from a higher education background, and were therefore more difficult to engage and motivate than the other pupils [218].

RQ9: Do novices feel more present, immersed and engaged in phase two than in phase one?

Overall both phases showed that the immersive use of AR interfaces in the collaborative learning scenarios increased the level of presence to that of a real working group. Specifically, the AR glasses showed highly significant differences from the other interfaces with

regards to presence. While the AR-based handheld devices in the learning scenarios were also associated with a higher level of presence compared to reality, their performance is still lower than that of the AR-based glasses and in some scenarios were quite convergent with that of the VR-based interfaces. This is possibly because participants felt distracted when moving their hands to communicate while interacting with the game board. In this study we hypothesised that collaboration in reality, especially when playing cards game, is ideal as it ensures a high level of presence, immersion and engagement. However, we found that within the collaborative mixed-reality learning groups, interventions with wearable or handheld interfaces could increase the levels of immersion and engagement to levels mimicking the reality. Perhaps, one reason could be that the feeling of immersion and engagement relatively consider factors such as challenge, emotional involvement and absorption in the applied questionnaires, which were unlike presence, which considered factors such as sensory and realism. Thus, this might to some extent explain the increase in their levels over a traditional group working or playing.

6.4 Summary

This chapter discussed the experimental findings in three sections. It opened with a discussion of the phase one results, then the phase two results, and then a comparison of the two experimental groups. In both phases, the presence, immersion and engagement levels of the participants were in some MiRTLE+ scenarios better than those of the web-based scenario, almost mimicking those of the control group. Moreover, learners with the MiRTLE+ scenarios showed better learning gain scores than those using the web-based scenario, although this difference was not significant. Specifically, the AR-based interfaces played a key role in enhancing the levels of presence, immersion, engagement and learning effectiveness in the MiRTLE+ scenarios. Within the teaching experience results, however, a mixture of VR-based and AR-based interfaces elicited more positive responses than web-based or only AR-based scenarios. These phase-based discussions also addressed the relationships

between the teaching experience and learning improvements within these variables. Overall our experimental results in phase one and phase two indicate that the scenarios involving more immersive AR interfaces (mainly the wearable interfaces) increased the levels of presence, immersion and engagement for the participants. Moreover, the learners' performance in such settings was quite similar to that of a group of learners in a real collaborative space. This is quite remarkable considering that these interfaces, specifically the wearable AR and VR glasses, for mixed reality platforms are still in their infancy and under constant development/improvement.

The next chapter presents the conclusion and final thoughts of this study as well as the challenges and avenues for future work.

Chapter 7

Conclusions and Future Directions

This thesis sought to explore the affordances in education of collaborative MR learning spaces for different learning scenarios, different levels of user expertise and different user interfaces by measuring various affected HCI factors. This goal was achieved by developing and implementing an architectural model to enable users with different levels of expertise using different VR and AR interfaces to collaborate and interact on a learning task (i.e. a game-based activity) in a collaborative MR space, as well as by adapting and using HCI frameworks to measure related factors of presence, immersion and engagement. To achieve these objectives, an extensive investigation of related prior research and studies was conducted (chapter two). Then, related pedagogical and technical theories were explored in order to form and structure our architectural model, MiRTLE+, as detailed in chapter three. In chapter four, the proof-of-concept implementation, including our adaption of the game activity to meet our learning task requirements, was explained, followed by the experimental design for our experiments. We reported our findings for all measured factors, including user experience and teaching experience, in chapter five. This was followed by a detailed discussion of the findings in chapter six. Finally, this chapter (seven) summarises the overall findings of the thesis and discusses achievements and future avenues for study.

7.1 Summary of achievements

This research posed the first hypothesis that *"it is possible to devise a conceptual architectural model capable of gathering a group of remote and local experts and novices in different learning scenarios to exchange learning content in a collaborative MR learning space"* (hypothesis 1). To validate this hypothesis, the theoretical model was constructed to address the gaps in the literature of a small collaborative learning group of mixed and augmented reality spaces. The model was capable of serving the functionalities from user interfaces, mixed and augmented environments, voice communication to web-based and other shared objects. This model's activities were also classified based on known mixed reality activities classifications such as (MiReSL-LA classification). Based on the virtuality continuum, the activities can be virtual-based, mixed reality-based, and augmented reality-based. However, they can only be synchronous activities that involved the execution of activities between four participants at the same time. The activities can also be learning such as a lecture activity or support activities such as a coursework. Moreover, the model supports role-play (i.e. role definitions performed within game structures) activities and task-based activities (i.e. events result in a deliverable). Also, this model activities can be applied to a collaborative group of users rather than single-user activities. Therefore, in order to generalise this model, the following learning design specifications should be considered:

- Learning type - that is, whether the activity is formal (e.g. practical classes) or informal (e.g. discussion meeting).
- Content - that is, web-based content, AR content or VR content.
- Learning environments where users meet and work on. These environments range from a VR environment, an AR environment to a MR environment.
- User interface - that is, the technology device used to communicate with the system. It can be a PC screen, handheld or head-mounted displays.

- Collaborative activity that is where two or more users can meet and collaborate on a learning activity.
- Environment simulation - that is, where the virtual environment should be simulated as the real environment in terms of shape, size and content.

In the second hypothesis, *"the existence of collaborative AR and MR learning application scenarios will increase novices' learning performance with experts due to greater engagement, a greater sense of presence and immersion and higher learning outcomes and will support the experts' teaching experiences in producing these higher level of results."*, To validate the second part of this study's hypothesis, eight learning scenarios for MiRTLE+ were designed and experimented in two phases to be compared with a web-based scenario (as a common traditional technology being used) and the control group (i.e. without using technology). The first phase consisted of four scenarios, which used iPads interfaces and PC screens interfaces, whereas the second phase involved the other four scenarios that involved AR glasses and a VR head-mounted display. In each scenario, two novices and two experts were distributed on the game table with their interface devices. However, the setting of each player was varied from scenario to another to ensure that all possible cases of users collaboration were considered in our MiRTLE+ model. For example, both novices used iPads and were connected locally from the iClassroom, and experts were connected remotely by using PC screens in the phase one, scenario three and so on and so forth for other scenarios. The evaluation was performed on both phases scenarios as well as between phases with the control group and the web-based group.

Novices using our 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, immersion and engagement were positively related to learning outcomes in almost all learning scenarios. Moreover, 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. This was

not the case for the engagement variable which might be explained from the literature that engagement levels are sometimes not clearly distinguished amongst adult learners. However, 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 (more specifically, immersive glasses) were highly considered to be the most influential variables to increase the users sense of presence and immersion, and their learning outcomes. We concluded that although these technology interfaces are still under development and investigation, they have a high potential for effectiveness in learning and teaching 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.

7.2 Revisiting contributions and hypotheses

The chief novelty of this research stems from its investigation of the ways in which applying different collaborative MR and AR learning spaces affects learning effectiveness and other HCI factors related to learning and teaching. Thus, this study makes two primary contributions:

1. Developing a theoretical model of MR and AR collaborative teaching and learning platforms for education.

2. Integrating different HCI interfaces in different MR and AR collaborative learning scenarios to increase learning and teaching performance by enhancing sense of presence, immersion and engagement.

As part of the contributions of this study, this thesis proposed in chapter 3 the MiRTLE+ model - a conceptual architectural model for a collaborative technology-enhanced learning spaces that encompasses mixed and augmented reality learning environment, shared web-based content, different users interfaces and assessment. This model addressed limitations of

current collaborative mixed and augmented reality learning spaces, allowing a group of users from different levels of expertise and from different locations by using different interfaces to communicate and achieve learning activities, and addressing the challenge of synchronisation of users interaction, voice communication, web-shared learning tasks and distributed objects. To implement the proposed model, this research presented a prototype software and hardware architecture in chapter 4, which scaled up learning spaces by bridging between geographically distributed environments using different mixed and augmented reality interface devices and shared objects, thereby enabling local and remote users' perception as present into one large common environment. This thesis also presented an evaluation of the MiRTLE+ prototype (chapter 5 and 6) through HCI user studies in a case study between users of eight different learning scenarios including an analysis of users' sense of presence, immersion, engagement and learning and teaching effectiveness.

Beyond these main contributions, the project also gave rise to two secondary contributions:

1. Developing an error-based system to enable experts or experimenters to keep track of novices' errors during game play. (Chapter 4)

2. Completing a pre-design survey of experts' views concerning the rules of the Uno card game to validate the rules in our error-based system. (Chapter 4)

Based on the aforementioned contributions, we hypothesised that (1) it is possible to devise a conceptual architectural model capable of gathering a group of remote and local experts and novices in different learning scenarios to exchange learning content in a collaborative MR learning space; (2) the existence of collaborative AR and MR learning application scenarios will increase novices' learning performance with experts due to greater engagement, a greater sense of presence and immersion and higher learning outcomes and will support the experts' teaching experiences in producing these higher level of results. To test these hypotheses, the study included two phases. During phase one, novices and experts used tablets and PC screens between local and remote spaces, respectively. During phase two, students and experts used glasses in both situations. From this, it was expected that the novices'

learning performance and the experts' teaching experiences, and levels of presence, immersion and engagement during the first phase would be higher for those using the new technology than for those using traditional web-based applications and lower than for those learning in real, traditional learning classrooms. Furthermore, during the second phase, the factor measurements for the experimental classroom were expected to be quite similar to those of the real, traditional classroom and to be higher than those of web-based applications.

7.3 Future work

Due to the time constraints of this PhD study, we covered and considered only those areas of work that were most relevant for answering our questions. However, there were some areas identified from the literature that could not be covered, as well as some aspects that appeared from our findings that need to be addressed in future work, as follows:

- 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. [204]), 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.

- Other factors might play a key role in the students' responses regarding their levels of engagement. This potential issue was verbally noted by a participant who said, 'I can only see a 3D person. Oops, there is her name on it'. This ambiguity about the identity of the virtual participants could be addressed by capturing the participants' faces during their registration onto the system and simulating these faces on their avatars [219].

- The proof-of-concept implementation (MiRTLE+) used a particular set of interfaces; that is, normal PC screens, handheld devices and head-mounted displays. An area for future work may be the integration of other types of interfaces such as the use of Immersive Display[1] that would pose different findings in this study's factors. The Immersive Desk display is a semi-spherical sectioned screen with a desk attached, enabling interaction with the physical environment and a natural position for achieving learning tasks, with a free-range of head movement without the need of any intrusive body instrumentation (e.g. special glasses).

- Collaboration within the proposed MiRTLE+ framework was focused on a collaborative game-based activity in informal education settings, where this activity is specifically applied to achieve specific goals that novices learn basic knowledge about the game rules. However, different formal learning topics (e.g. a coursework for solving mathematics problems) could usefully be investigated for assessing different HCI aspects. For example, there might be a question about whether this type of collaboration in more formal learning instead of using games in MiRTLE+ could decrease the levels of presence, immersion and engagement.

- Inside the real iClassroom, the participant movements can be tracked using their virtual partners based on what they are looking at and the markers what they are pointing at, which are located on the real chairs. It may be possible to allow virtual users to recognise their real partners when moving among chairs through a tracking system within the real environment. By this, I mean a tracking system such as Kinect or a set of smart tracking cameras set up around the iClassroom wall that could be integrated into the MiRTLE+ system to allow 1) logging into the system once entering the classroom, 2) tracking users movement from the real environment and simulate it in the virtual world.

- The proof-of-concept MiRTLE+ was applied on adults for the evaluation of the learning

[1] www.immersivedisplay.co.uk

task and some of the psychological HCI aspects such as engagement. However, it could be interesting to investigate this system on children to assess the engagement as Martin [218] stated that the age of participants plays a key role in engagement.

- In the proof-of-concept of this study, the expert user is a user that is knowledgable about the game activity rules allocated for this study's experiments. One of his/her roles is to deliver the knowledge to the novice partner as well as assess the improvement of the novice. However, considering applying the MiRTLE+ model on a large scale may result in difficulty of finding an expert for each novice. Hence, a development of intelligent autonomous virtual expert agents could also be performed to investigate their effectiveness in such collaborative learning scenarios comparing with human experts. Moreover, it is useful to investigate novices' responses and achievements when collaborating with expert agents compared with novices who collaborate and interact with human experts.

Appendices

.1 Research instruments

Research Participants Information Sheet

Certification

I, (Ahmed Alzahrani) certify that the details of this project have been fully explained and described and my contact details have been provided to the participants for their replies, communications or inquiries.

What is the purpose of the study?

The aims of the evolution have been set by the researcher. I propose to measure students learning effectiveness, sense of presence, engagement and immersion through using a mixed and augmented reality collaborative learning space. I also consider how students from different levels of knowledge and distances may benefit from one another in such spaces.

Do the participants have to take part?

Your participation is voluntary. I would like you to consent to participate in this study as I believe that you can make an important contribution to the research. If you do not wish to participate you do not have to do anything in response to this request. I am asking you to take part in the research because I believe you can provide important information to me that may be relevant to the evaluation that I am undertaking.

What will the participations do if they take part?

If you are happy to participate in the research I will ask you to read this information sheet, sign the consent form. When I receive this you will be asked to enrol yourself in a simple learning task (playing the Uno card) either remotely or locally. Then you will be given a survey to fill in after the experiment. The researcher will contact you to discuss your participation in the next experiment once you become expert. At that point we can confirm your participation and make arrangements for you to meet for the next experiment.

What are the possible benefits of taking part?

Whilst there may be no personal benefits to your participation in this study, the information you provide can contribute to the future development of E-learning when using up-to-date mixed and augmented reality technologies.

Will the participants'' taking part in the study be kept confidential?

All information you provide to us will be kept confidential. Only the researcher will have access to it.

What will happen to the results of the research study?

All information provided by you will be stored anonymously on a computer with analysis of the information obtained undertaken by the researcher based at University of Essex. The results from this analysis will be available in one or more of the following sources; the researcher PhD thesis, scientific papers in peer reviewed academic journals; presentations at conferences or local seminars.

Participant Consent Form

Title: Assessment of Users Engagement, Sense of Presence, Immersion and the Impact on Learning Outcomes in a Mixed and Augmented a Reality Collaborative Learning Space

I wish to participate in the above named project. ☐

I have read the participant information sheet for the above research project and understand the following:

1. That I am free to withdraw at any time. ☐
2. That all information I provide will be dealt with in a confidential manner. ☐
3. I agree that the researcher may contact me. ☐

Name: …….

Signed: …….

Date: …….

Phase	☐ One ☐ Two
Please, choose your level of expertise in playing the UNO?	☐ Novice ☐ Expert
Please, choose your location when you are doing the experiment?	☐ Remote ☐ Local
Please, choose your interface	☐ Glasses ☐ Screen ☐ iPad
Scenario	☐ 1 ☐ 2 ☐ 3 ☐ 4

Personal information

Full name: (You should not write it if you signed above)	
Gender:	☐ Male ☐ Female ☐ Preferred not to say
Age:	☐ 18-20 ☐ 21-25 ☐ 26-30 ☐ 31-35 ☐ 36-40 ☐ Above 40
Degree major: (you are studying now or your last qualification)	☐ Bachelor's degree – undergraduate ☐ MSc degree – postgraduate ☐ PhD – postgraduate ☐ Other qualifications: level unknown (including foreign qualifications)
Background: (You may choose more than one)	☐ I used Augmented Reality technology before ☐ I have been involved in an a mixed reality before ☐ I used flash games before ☐ I used second life or other 3D virtual environment before ☐ I have been involved in an immersive education environment before ☐ I used immersive glasses before (e.g. Oculus Rift or Meta) ☐ I have NOT used in any of the above-mentioned technologies
Have you ever played any cards game in your life?	☐ Yes ☐ No ☐ I cannot remember
Have you played the UNO game before?	☐ Yes ☐ No ☐ I cannot remember
Do you know the UNO game rules?	☐ Yes ☐ No ☐ To some extent
Please, choose your level of expertise in playing the UNO?	☐ Novice ☐ Expert
Please, choose your location when you are doing the experiment?	☐ Remote ☐ Local

User experience questionnaire

Part 4: Measuring user experience questionnaire: Please assess your experience when playing Uno on the Website platform by ticking one circle per line.

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

Engagement

Part 6: Measuring Engagement: Please tick your experience for each statement on the scale: not at all, a little, moderate, much and very much.

Q1) It was boring

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q2) It was engaging

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q3) It was fun

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q4) I lost track of time

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q5) I felt immersed in the depicted situation

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q6) I felt excited

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q7) I felt awkward

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q8) I felt spaced out.

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q9) I could not tell that I am getting tired

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q10) My thoughts go fast

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q11) I played without thinking about how to play

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q12) Playing seemed automatic

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q13) I really got into the game

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q14) I felt like I just cannot stop playing

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Q15) Time seemed to kind of stand still or stop

☐ *Not at all* ☐ *A little* ☐ *Moderate* ☐ *Much* ☐ *Very much*

Presence

Part 7: Measuring Presence: Please select your experience for each question on the scale: Not compelling, moderately compelling, very compelling or not applicable:

Q1)How much were you able to control events?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q2)How natural did your interactions with the environment seem?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q3)How responsive was the environment to actions that you performed?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q4)How completely were *a*ll of your senses engaged?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q5)How much did the visual aspects of the environment involve you?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q6)How much did the auditory aspects of the environment involve you?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q7)How natural was the mechanism which controlled movement through your environment (i.e. virtual or real)?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q8)How aware were you of events occurring in the real world around you?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q9)How aware were you of your display and control devices?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q10) How compelling was your sense of game objects/players moving on the table?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q11) How inconsistent or disconnected was the information coming from your various senses?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q12) How much did your experiences based in your environment (i.e. virtual, augmented or Web-based environment) seem consistent with your real-world experiences?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q13) Were you able to anticipate what would happen next in response to the actions that you performed?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q14) How completely were you able to actively play or interact within your environment (i.e. the real, virtual or augmented) using vision?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q15) How well could you identify sounds?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q16) How well could you localise sounds?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q17) How well could you actively play or interact within your environment (i.e. the real, virtual or web-based environment) using touch/ gesture / or mouse-keyboard?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q18) How compelling was your sense of moving on the chair in the virtual environment/ real environment?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q19) How closely were you able to examine game objects/players?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q20) How well could you examine game objects/players from multiple viewpoints?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q21) How well could you move or manipulate game objects in your environment (i.e. the real, virtual environment or web-based platform)?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q22) To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?

Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q23) How involved were you in your environment (i.e. virtual, real environment or web-based platform) experience?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q24) How distracting was the control mechanism?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q25) How much delay did you experience between your actions and expected outcomes?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q26) How quickly did you adjust to the virtual, real or web environment experience?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q27) How proficient in moving, playing and interacting within your environment (i.e. virtual, real or web-based environment) did you feel at the end of the experience?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q28) How much did the visual display quality interfere or distract you from performing assigned tasks (cards game) or required activities?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

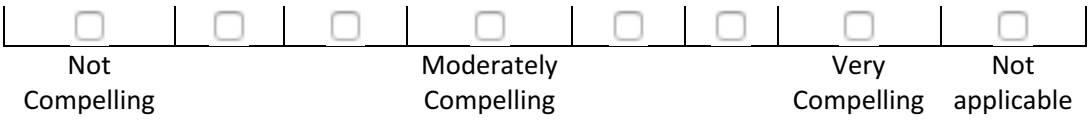
Q29) How much did the control devices interfere with the performance of assigned tasks or with other activities?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

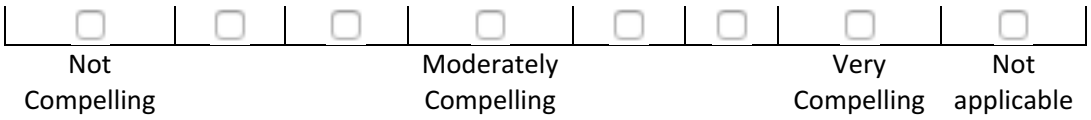
Q30) How well could you concentrate on the assigned tasks (cards game) or required activities rather than on the mechanisms used to perform those tasks or activities?

☐	☐	☐	☐	☐	☐	☐	☐
Not Compelling			Moderately Compelling			Very Compelling	Not applicable

Q31) Did you learn new techniques that enabled you to improve your performance?



Q32) Were you involved in the experimental task to the extent that you lost track of time?



Immersion

Part 8: Measuring Immersion: Please answer the following questions by circling the relevant number. In particular, remember that these questions are asking you about how you felt at the end of the task:

Q1) To what extent did the game task hold your attention in this environment?

1	2	3	4	5	Not
Not at all				A lot	applicable

Q2) To what extent did you feel you were focused on doing the learning tasks?

1	2	3	4	5	Not
Not at all				A lot	applicable

Q3) How much effort did you put into achieving the task?

1	2	3	4	5	Not
Not at all				A lot	applicable

Q4)Did you feel that you were trying you best?

1	2	3	4	5	Not
Not at all				Very much so	applicable

Q5)To what extent did you lose track of time?

1	2	3	4	5	Not
Not at all				A lot	applicable

Q6)To what extent did you feel consciously aware of being in the real world whilst playing?

1	2	3	4	5	Not
Not at all				Very much so	applicable

Q7)To what extent did you forget about your everyday concerns?

1	2	3	4	5	Not
Not at all				A lot	applicable

Q8)To what extent were you aware of your self in your surroundings?

1	2	3	4	5	Not
Not at all				Very aware	applicable

Q9)To what extent did you notice other events taking place around you?

1	2	3	4	5	Not
Not at all				A lot	applicable

Q10) Did you feel the urge at any point to stop playing and see what was happening around you?

1	2	3	4	5	Not
Not at all				Very much so	applicable

Q11) To what extent did you feel that you were interacting with the game environment?

1	2	3	4	5	Not
Not at all				Very much so	applicable

Q12) To what extent did you feel as though you were separated from your real- world environment? (”…other real-world events” for control group)

1	2	3	4	5	Not
Not at all				A lot	applicable

Q13) To what extent did you feel that the game task was something you were experiencing, rather than something you were just doing?

1	2	3	4	5	Not
Not at all				Very much so	applicable

Q14) To what extent was your sense of being in the experiment environment stronger than your sense of being in the real world?

1	2	3	4	5	Not
Not at all				Very much so	applicable

Q15) At any point did you find yourself become so involved that you were unaware you were even playing?

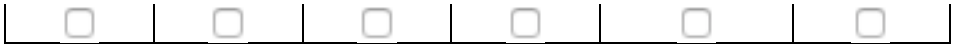
1	2	3	4	5	Not
Not at all				Very much so	applicable

Q16) To what extent did you feel as though you were achieving the game according to you own will?



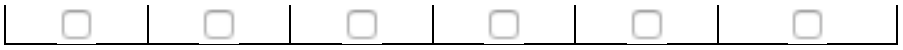
1	2	3	4	5	Not
Not at all				Very much so	applicable

Q17) To what extent did you find the game task challenging?



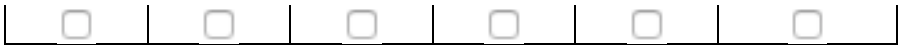
1	2	3	4	5	Not
Not at all				Very difficult	applicable

Q18) Were there any times during the task in which you just wanted to give up?



1	2	3	4	5	Not
Not at all				A lot	applicable

Q19) To what extent did you feel motivated while playing in the environment?



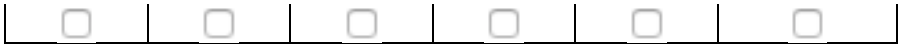
1	2	3	4	5	Not
Not at all				A lot	applicable

Q20) To what extent did you find the system easy to use?



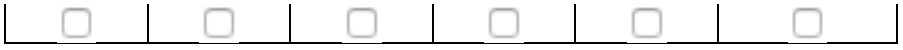
1	2	3	4	5	Not
Not at all				Very much so	applicable

Q21) To what extent did you feel like you were making progress towards the end of the game task?



1	2	3	4	5	Not
Not at all				A lot	applicable

Q22) How well do you think you performed in the game task?



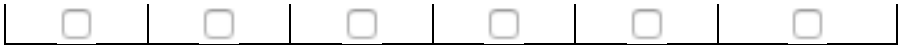
1	2	3	4	5	Not
Very poor				Very well	applicable

Q23) To what extent did you feel emotionally attached to the game task?



1	2	3	4	5	Not
Not at all				Very much so	applicable

Q24) To what extent were you interested in seeing how the game's events would progress?



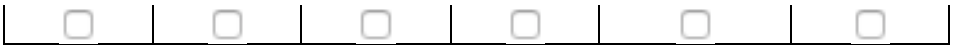
1 2 3 4 5 Not
Not at all A lot applicable

Q25) How much did you want to "win" the game?



1 2 3 4 5 Not
Not at all Very much so applicable

Q26) Were you in suspense about whether or not you would win or lose the game?



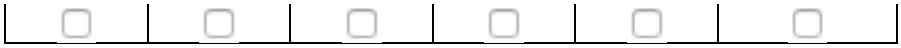
1 2 3 4 5 Not
Not at all Very much so applicable

Q27) At any point did you find yourself become so involved that you wanted to speak to the game directly?



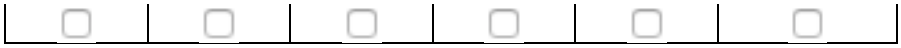
1 2 3 4 5 Not
Not at all Very much so applicable

Q28) To what extent did you enjoy the graphics and the imagery?



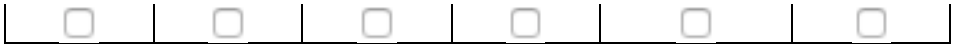
1 2 3 4 5 Not
Not at all A lot applicable

Q29) How much would you say you enjoyed playing the game?



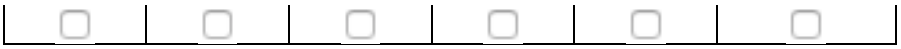
1 2 3 4 5 Not
Not at all A lot applicable

Q30) When interrupted, were you disappointed that the game task was over?



1 2 3 4 5 Not
Not at all Very much so applicable

Q31) Would you like to play the game again in this environment?



1 2 3 4 5 Not
Definitely Definitely applicable
No Yes

Pre-test

<u>Part 9: Measuring learning effectiveness:</u> please select (the most correct answer) from the following multiple-choice questions:

Q1) Based on the Uno rules, how many cards should each player get before starting the game:

a. 6
b. 7
c. 8
d. 9

Q2) Which best card should you play when the top card is  **:**

a. 
b. 
c. 
d. 

Q3) Which best card should you play when the top card is  **and the next opponent player has got <u>one</u> card:**

a. 
b. 
c. 
d. 

Q4) How to win in playing the Uno card game:

a. By collecting more points based on your hand.

b. By playing all of your cards to finish before the opponent.

c. By decreasing the total amount of your hand cards numbers.

d. By increasing the total amount of your hand cards numbers.

Q5) What action you do if you do not have a card that matches the top card:

a. Pass the turn to the next player.

b. Withdraw one card.

c. Play the Wild card if you have got one.

d. Play any colour of Draw 2 card that dose not match the top card colour.

Q6) What the Revers card does when playing as partnership based on the UNO official website:

a. Skip the next player.

b. Revers the turn order.

c. It is still your turn to play another card.

d. Nothing from above.

Q7) What is one of the best strategies to make the opponent NOT to win:

a. Increase his/her hands cards.

b. Decrease his/her hands cards.

c. Increase his/her points.

d. Decrease his/her points.

Q8) What is the purpose of playing a Withdrawing card (e.g. +2):

a. Add more points to my score.

b. Add more cards on the opponent player.

c. Decrease more points from the opponent player.

d. Decrease more cards from the opponent player.

Q9) What must the next player do when he forgets to say Uno:

a. His/her turn will be skipped.

b. He must withdraw one card.

c. Decrease more points from the opponent player.

d. Continue to the next player and allow him to say Uno again.

Q10) The score for the winner in each round will be based on?

a. The summation of other left cards points.

b. The count of other players' left cards.

c. 10 points will be given for each left cards of other players.

d. All of the above are correct.

Post-test (novices)

Part 10: Measuring learning effectiveness: please select (the most correct answer) from the following multiple-choice questions:

Q1) Based on the Uno rules, how many cards should each player get before starting the game:

a. 6
b. 7
c. 8
d. 9

Q2) What the Revers card does when playing as partnership based on the UNO official website:

a. Skip the next player.
b. Revers the turn order.
c. It is still your turn to play another card.
d. Nothing from above.

Q3) Which best card should you play when the top card is  **and the next opponent player has got one card:**

a. 
b. 
c. 
d. 

Q4) How to win in playing the Uno card game:

a. By collecting more points based on your hand.
b. By playing all of your cards to finish before the opponent.
c. By decreasing the total amount of your hand cards numbers.
d. By increasing the total amount of your hand cards numbers.

Q5) **What action you do if you do not have a card that matches the top card:**

a. Pass the turn to the next player.

b. Withdraw one card.

c. Play the Wild card if you have got one.

d. Play any colour of Draw 2 card that dose not match the top card colour.

Q6) **Which best card should you play when the top card is:**

a. 

b. 

c. 

d. 

Q7) **What is one of the best strategies to make the opponent NOT to win:**

a. Increase his/her hands cards.

b. Decrease his/her hands cards.

c. Increase his/her points.

d. Decrease his/her points.

Q8) **What is the purpose of playing a Withdrawing card (e.g. +2):**

a. Add more points to my score.

b. Add more cards on the opponent player.

c. Decrease more points from the opponent player.

d. Decrease more cards from the opponent player.

Q9) What must the next player do when he forgets to say Uno:

a. His/her turn will be skipped.

b. He must withdraw one card.

c. Decrease more points from the opponent player.

d. Continue to the next player and allow him to say Uno again.

Q10) The score for the winner in each round will be based on?

a. The summation of other left cards points.

b. The count of other players' left cards.

c. 10 points will be given for each left cards of other players.

d. All of the above are correct.

Teaching experience (experts)

Part 11: Measuring teaching experiences: please select your experience for each question on the scale: Strongly disagree, disagree, agree or strongly agree:

Q1)Learning new technologies such as a PC, iPad or head- mounted display is confusing for me as an expert:

☐	☐	☐	☐
1 Strongly agree	2 Agree	3 Disagree	4 Strongly disagree

Q2)I get anxious when using new technologies such as a PC, iPad or head-mounted display because I don't know what to do if something goes wrong:

☐	☐	☐	☐
1 Strongly agree	2 Agree	3 Disagree	4 Strongly disagree

Q3)I am confident in trying to learn new technologies on my own:

☐	☐	☐	☐
1 Strongly agree	2 Agree	3 Disagree	4 Strongly disagree

Q4)I feel comfortable about my ability to work with computer technologies:

☐	☐	☐	☐
1 Strongly agree	2 Agree	3 Disagree	4 Strongly disagree

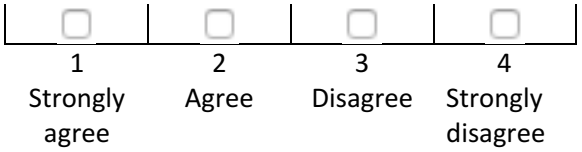
Q5)I enjoy finding new ways that my partner (novice) and I can use technology in the classroom:

☐	☐	☐	☐
1 Strongly agree	2 Agree	3 Disagree	4 Strongly disagree

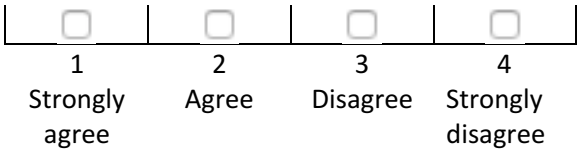
Q6)I get anxious when using technology with my partner (novice):

☐	☐	☐	☐
1 Strongly agree	2 Agree	3 Disagree	4 Strongly disagree

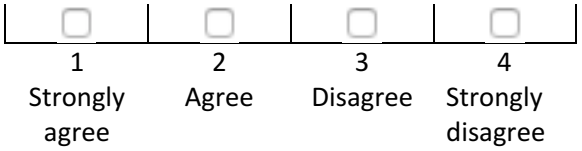
Q7)I am confident with my ability to troubleshoot when problems arise while using technology:



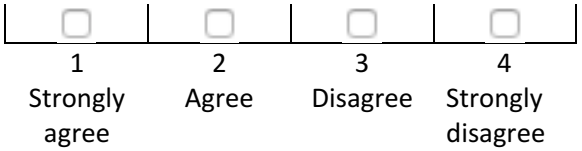
Q8)Learning new technologies that I can use in the classroom is important to me:



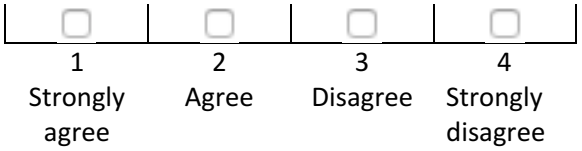
Q9)Technology can be an effective learning tool for one to one teaching:



Q10) Using technology to communicate with others allows me to be more effective in my knowledge transfer:



Q11) My partner (novice) get excited when they use technology in the learning process:



Any other comments – please feel free to add your comments about your experience in the following box

Learning data collection tool (error-based tool)

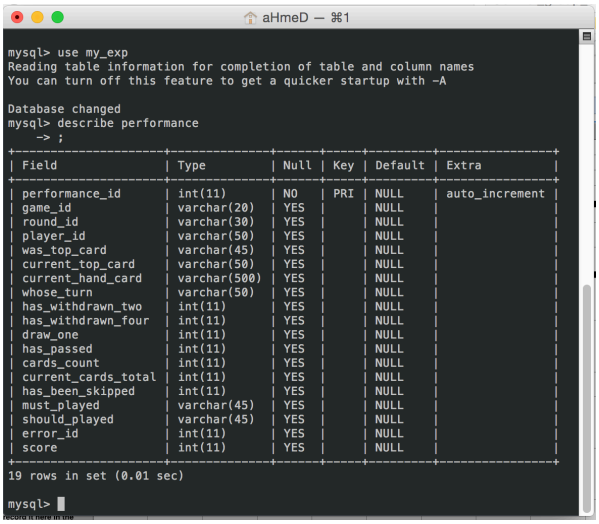
a) Learning evaluation sheet for the control group:

Errors	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6	Round 7	Round 8	Round 9	Round 10
Not your turn										
by mistake										
has been drawn										
has been skipped										
Differen card										
Not the same colour or number										
Not the same requested colour										
Did not withdraw (i.e. when he says: I do not have a card, what should I do?)										
Withdrew and did not pass or play (i.e. when you wait him/her and then s/he says I don't have a card to play)										
Play small numbers while having a big number										
Do not play the draw card at the proper time (i.e. when the opponent almost loses all of his cards)										
Did not play the Wild Colour card when s/he does not have the same colour (i.e. when s/he askes about it)										
Other errors, please record it here in the following cells.										

b) Games, rounds and time sheet for the control group:

	Round 1				Round 2				Round 3			
	Time	Num of turns	Total scores	Winner team	Time	Num of turns	Total scores	Winner team	Time	Num of turns	Total scores	Winner team
Game 1												
Game 2												
Game 3												
Game 4												
Game 5												
Game 6												
Game 7												
Game 8												
Game 9												

c) Games, rounds and time database table for the experimental and web groups:

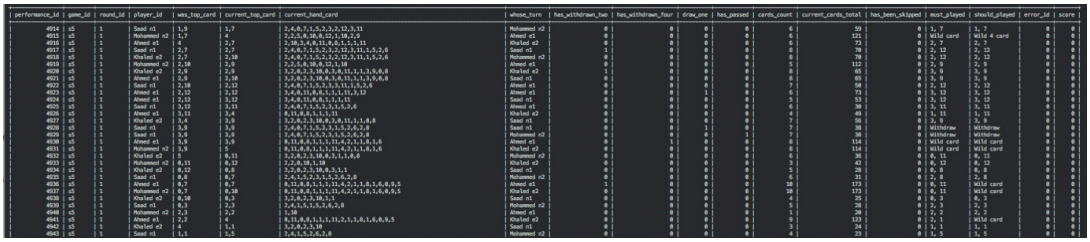


```
aHmeD — ⌘1

mysql> use my_exp
Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A

Database changed
mysql> describe performance
    -> ;
+---------------------+---------------+------+-----+---------+----------------+
| Field               | Type          | Null | Key | Default | Extra          |
+---------------------+---------------+------+-----+---------+----------------+
| performance_id      | int(11)       | NO   | PRI | NULL    | auto_increment |
| game_id             | varchar(20)   | YES  |     | NULL    |                |
| round_id            | varchar(30)   | YES  |     | NULL    |                |
| player_id           | varchar(50)   | YES  |     | NULL    |                |
| was_top_card        | varchar(45)   | YES  |     | NULL    |                |
| current_top_card    | varchar(50)   | YES  |     | NULL    |                |
| current_hand_card   | varchar(500)  | YES  |     | NULL    |                |
| whose_turn          | varchar(50)   | YES  |     | NULL    |                |
| has_withdrawn_two   | int(11)       | YES  |     | NULL    |                |
| has_withdrawn_four  | int(11)       | YES  |     | NULL    |                |
| draw_one            | int(11)       | YES  |     | NULL    |                |
| has_passed          | int(11)       | YES  |     | NULL    |                |
| cards_count         | int(11)       | YES  |     | NULL    |                |
| current_cards_total | int(11)       | YES  |     | NULL    |                |
| has_been_skipped    | int(11)       | YES  |     | NULL    |                |
| must_played         | varchar(45)   | YES  |     | NULL    |                |
| should_played       | varchar(45)   | YES  |     | NULL    |                |
| error_id            | int(11)       | YES  |     | NULL    |                |
| score               | int(11)       | YES  |     | NULL    |                |
+---------------------+---------------+------+-----+---------+----------------+
19 rows in set (0.01 sec)

mysql>
```



Pre-survey to differentiate experts and novices (for email advertisement):

I am a PhD student, running an experiment in e-learning. In my experiment, I am using the Uno cards game.

I am in need of some participants who either know how to play Uno or not, so for the chance to participate, plus win a £ 5 Amazon gift card, please reply with the answering the following 3 questions.

1. Gender

- ○ Male
- ○ Female
- ○ Prefer not to say

---

2. Have you played the Uno cards game before? (Do not worry! I need people who know and do not know how to play)

- ○ Yes
- ○ No

---

3. Have you ever played any cards game in your life?

- ○ Yes
- ○ No

---

4. Have you played online games before?

- ○ Yes
- ○ No

---

5. Background: (You may choose more than one)

- ☐ I used Augmented Reality technology before
- ☐ I have been involved in an a mixed reality before
- ☐ I used flash games before
- ☐ I used second life or other 3D virtual environment before
- ☐ I have been involved in an immersive education environment before
- ☐ I have NOT used in any of the above-mentioned technologies

---

6. Please write your email in the following text box to allow the experimenter arrange with you for the experiment

Characters Remaining: 100

You have accessed this survey in TEST MODE. Your answers will not be recorded

Clear answers on page Submit

.2 Uno rules and errors categorisations

1.2 UNO SURVEY

1.2.1 Categorising Uno errors rules

I have listed all possible errors that the novices may do, and then categorised them into 3 categories: basic, intermediate and advanced. Then, a survey was created to be answered by people who have played the Uno in order to validate my proposed category as show below:

Part 2: This part is to classify the rules errors or strategic errors that the player may make during the game.

	If we assume that the errors of UNO of the novices and experts can be categorised into three levels: basic, intermediate and advanced, how would you classify the following errors?		
	Basic 1	Intermediate 2	Advanced 3
If it is a player's turn, and s/he keeps asking 'Is it my turn now?'			
If the player tries to play a card that does not match the colour or number			
If the player calls for a colour on the Wild card that s/he does not have a lot of			
If the player keeps passing the turn without withdrawing one card			
If the player does not say 'UNO' once s/he has only one card left			
If the player usually plays cards carrying small numbers before cards carrying big numbers of the same colour			
If the player does not play Draw 4 or Draw 2 cards when the next player is about to finish			
When the player does not play a card that has the same number but a different colour which s/he has a lot of			

<< Back Clear answers on page Next >>

1.2.2 Best choices of strategic play:

Furthermore, the survey also included various random game cases that the experts can identify the best choice card to play in each case, the following graphs show these cases with the results of the experts' choices:

Required Information

Part 1: This part is to rank all possible actions that the player can do in various scenarios during the game.

You are now playing the UNO cards game in a group of 4 players. Your hand cards are as shown in Figure 1, and it is your turn now. Keep in mind that in this scenario, the next player (your opponent) has 7 cards. You could do one of 4 actions as listed below. How would you rank them (1 = the highest priority; 4 = the lowest priority) ?



Figure 1

 -Please Rank-

 -Please Rank-

 -Please Rank-

 -Please Rank-

Withdraw

You are now playing the UNO cards game in a group of 4 players. If your hand cards are as shown in Figure 2, and it is your turn now. Keep in mind that in this scenario, the next player (your opponent) has 7 cards. You could do one of 3 actions as listed below. How would you rank them (1 = the highest priority; 3 = the lowest priority)?



Figure 2



-Please Rank-



-Please Rank-



-Please Rank-

Withdraw

You are now playing the UNO cards game in a group of 4 players. If your hand cards are as shown in Figure 3, and it is your turn now. Keep in mind that in this scenario, the next player (your opponent) has 3 cards. You could do one of 5 actions as listed below. How would you rank them (1 = the highest priority; 5 = the lowest priority)?



Figure 3

 -Please Rank-

 -Please Rank-

 -Please Rank-

 -Please Rank-

 -Please Rank-

Withdraw

You are now playing the UNO cards game in a group of 4 players. If your hand cards are as shown in Figure 4, and it is your turn now. Keep in mind that in this scenario, the next player (your opponent) has 3 cards. You could do one of 4 actions as listed below. How would you rank them (1 = the highest priority; 4 = the lowest priority)?



If the next opponent player has got 3 cards now

علماً بأن عدد أوراق اللاعب الخصم الذي يليك هو ٣

Figure 4

 -Please Rank-

 -Please Rank-

 -Please Rank-

 -Please Rank-

Withdraw

You are now playing the UNO cards game in a group of 4 players. If your hand cards are as shown in Figure 5, and it is your turn now. Keep in mind that in this scenario, the next player (your opponent) has 4 cards. You could do one of 5 actions as listed below. How would you rank them (1 = the highest priority; 5 = the lowest priority)?



If the next opponent player has got 4 cards now

علماً بأن عدد أوراق اللاعب الخصم الذي يليك هو ٤

Figure 5



-Please Rank-



-Please Rank-



-Please Rank-



-Please Rank-



Withdraw

<< Back Clear answers on page Next >>

40%

Required Information

You are now playing the UNO cards game in a group of 4 players. If your hand cards are as shown in Figure 6, and it is your turn now. Keep in mind that in this scenario, the next player (your opponent) has 3 cards. You could do one of 5 actions as listed below. How would you rank them? (1 = the highest priority; 5 = the lowest priority)



Figure 6


-Please Rank-


-Please Rank-


-Please Rank-


-Please Rank-


-Please Rank-

Withdraw

You are now playing the UNO cards game in a group of 4 players. If your hand cards are as shown in Figure 7, and it is your turn now. Keep in mind that in this scenario, the next player (your opponent) has 5 cards. You could do one of 4 actions as listed below. How would you rank them (1 = the highest priority; 4 = the lowest priority)?



Figure 7


-Please Rank-


-Please Rank-


-Please Rank-


-Please Rank-
Withdraw

You are now playing the UNO cards game in a group of 4 players. If your hand cards are as shown in Figure 8, and it is your turn now. Keep in mind that in this scenario, the next player (your opponent) has 5 cards. You could do one of 4 actions as listed below. How would you rank them (1 = the highest priority; 4 = the lowest priority)?



Figure 8

 -Please Rank-

 -Please Rank-

 -Please Rank-

 -Please Rank-

Withdraw

You are now playing the UNO cards game in a group of 4 players. If your hand cards are as shown in Figure 9, and it is your turn now. Keep in mind that in this scenario, the next player (your opponent) has 3 cards. You could do one of 4 actions as listed below. How would you rank them (1 = the highest priority; 4 = the lowest priority)?



Figure 9



-Please Rank-



-Please Rank-



-Please Rank-



-Please Rank-

Withdraw

<< Back Clear answers on page Next >>

60%

.3 Experiments instructions

Expert instructions

1. At the beginning, you or the other expert team will be the dealer.
2. You can teach your partner the rules of the game and correct him only before starting the game and between rounds.
3. The other expert can also share your knowledge. However, only one of you can talk at a time in order to transfer the correct knowledge to the novices.
4. Now, the game should start from the next player after the dealer (the player to dealer's right).
5. During the game, you are not allowed to talk to your partner, if he needs help, you may give him a hint. However, you need to record what did he ask about (in the timetable sheet).
6. After each round, you should evaluate your partner progress by using the given timetable sheet "Evaluating your Partner Progress".

Recap: Things to tell you partner from the rules (before starting the first round, and between rounds)

Goal of Uno!

The Goal of Uno is to be the first team to score 500 points. Points are scored by getting rid of all the cards in your hand before your opponent(s). You score points for cards left in your opponents' hands.

- Your partner should have the following knowledge about the game before starting and between rounds, **NOT during the round as we are simulating the reality**:
  1. What to play?
  2. When to say Uno?
  3. When to withdraw?
  4. When to pass?
  5. The strategic rules:
     a. When to play a Wild4 or Wild Colour card?
     b. What should you play if you have various number of the same colour?
     c. What should you play if the opponent will almost get rid of the cards?
- The game ends as soon as the 1st person from any team loses all of his/her cards.
- The target score for the whole session is 300 scores.
- The score points will be from cards left in your opponents' hands as well as your partner.

How to evaluate you partner

In the attached sheet "Evaluating your Partner Progress"; there is a number of errors that novices may make during the game. The experimenter task is also to observe him/her by filling in the column in each round.

For example: if the player tries to play while it is not his/her turn because of s/he has been drawn, you put a line in the box of 'has been drawn' under 'Not your turn' error as shown in the Figure 1.

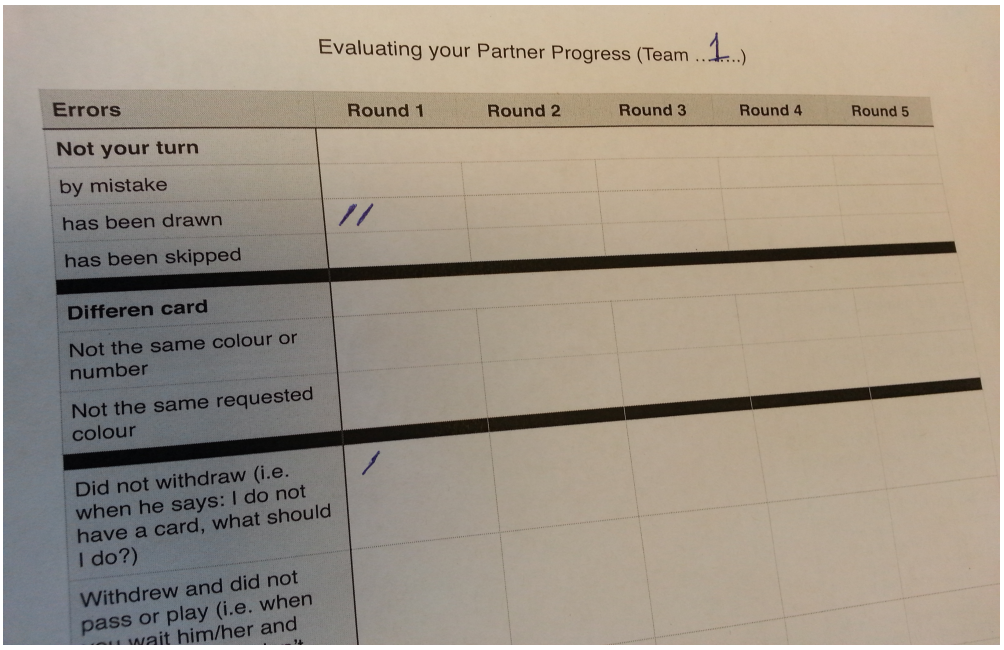


Figure 1: Player here made 3 errors in the Round 1 (2 not your turn and 1 did not withdraw)

Time, rounds and turns counters

The experimenter will also record the time taken for each round. The record will start when the first player lay out the first card and stop when the first person from any team loses all of his/her cards (i.e. in each round as shown in next figure 2).

	Round 1				Round 2				Round 3				Round
	Time	Num of turns	Total scores	Winner team	Time	Num of turns	Total scores	Winner team	Time	Num of turns	Total scores	Winner team	Time	Num of turns
Game 1														
Game 2														
Game 3														
Game 4														
Game 5														
Game 6														
Game 7														
Game 8														
Game 9														

Figure 2: Time recording sheet

Experiment 1_ control group

Video recording

There will be a video recording. The lenses will only point to the novices' hands cards and the current top card on the table.

Experiment 1_ control group

Novice instructions

1. You will learn the basic rules of playing the Uno card game as well as its strategic rules from either your expert partner or the other expert.
2. You are allowed to ask questions or query before starting the game (i.e. when the experts explain) and between the rounds.
3. In case you do not know that which card should you play, you only need to guess and if your guessing was a mistake, your partner or the other expert will correct you.

Time, rounds and turns counters

The experimenter will record the time taken for each round. The record will start when the first player lay out the first card and stop when the first person from any team loses all of his/her cards (i.e. in each round).

Video recording

There will be a video recording. The lenses will only point to the novices' hands cards and the current top card on the table.

Phase 1_ scenario 1

<table>
<tr><td colspan="4">Meet at iClassroom to sign the contest form</td></tr>
<tr><td>Local Expert</td><td>Local Novice</td><td>Remote expert</td><td>Remote novice</td></tr>
<tr><td>Sit on chair 2</td><td>Sit down on chair 4</td><td>From your office</td><td>From your office</td></tr>
<tr><td>Pick up the iPad and run the MiRTLE+ app</td><td>Pick up the iPad and run the iClassroom app</td><td>Run the MiRTLE+ app from your desktop</td><td>Run the MiRTLE+ app from your desktop</td></tr>
<tr><td>Click register button
Only register:
Username
Password
Gender
Then click Submit</td><td>Click register button
Only register:
Username
Password
Gender
Then click Submit</td><td>Click register button
Only register:
Username
Password
Gender
Then click Submit</td><td>Click register button
Only register:
Username
Password
Gender
Then click Submit</td></tr>
<tr><td>Choose:
Local
Expert
Team1
Then click viClassrom</td><td>Choose:
Local
Novice
Team1
Then click viClassrom</td><td>Choose:
Remote
Expert
Team2
Then click viClassrom</td><td>Choose:
Remote
Expert
Team2
Then click viClassrom</td></tr>
<tr><td>Join the just created iClassroom</td><td>Join the just created iClassroom</td><td>Click Create new iClassroom</td><td>Join the just created iClassroom</td></tr>
<tr><td>You can point to the to see your opponent team</td><td>You can point to the to see your opponent team</td><td>Right click on the mouse to enable looking around

Escape key from the keyboard to control events</td><td>Right click on the mouse to enable looking around

Escape key from the keyboard to control events</td></tr>
<tr><td>Click on Press to talk for talking with all group</td><td>Click on Press to talk for talking with all group</td><td>Click on Press to talk for talking with all group</td><td>Click on Press to talk for talking with all group</td></tr>
<tr><td>Click on Start playing</td><td>Click on Start playing</td><td>Click on Start playing</td><td>Click on Start playing</td></tr>
<tr><td>Then, click on Register player name</td><td>Then, click on Register player name</td><td>Then, click on Register player name</td><td>Then, click on Register player name</td></tr>
<tr><td>Enter your username + e1 (e.g. John e1)</td><td>Enter your username + n1 (e.g. John n1)</td><td>Enter your username + e2 (e.g. John e2)</td><td>Enter your username + n2 (e.g. John n2)</td></tr>
<tr><td>Create a game session with a name s1</td><td rowspan="4">Wait for logging in instruction from the local expert E1</td><td rowspan="4">Wait for logging in instruction from the local expert E1</td><td rowspan="4">Wait for logging in instruction from the local expert E1</td></tr>
<tr><td>Ask through the mic n2 to login on the game s1</td></tr>
<tr><td>Then, ask through the mic e2 to login on the game s1</td></tr>
<tr><td>Then, ask through the mic n1 to login on the game s1</td></tr>
<tr><td colspan="4">The target is to reach 300 point to win</td></tr>
<tr><td>Expert can explain the rules ONLY before starting the game and between rounds</td><td>You can ask about things ONLY before starting the game or between rounds</td><td>Expert can explain the rules ONLY before starting the game and between rounds</td><td>You can ask about things ONLY before starting the game or between rounds</td></tr>
<tr><td></td><td>If you do not know what to play, just guess and play.</td><td></td><td>If you do not know what to play, just guess and play.</td></tr>
</table>

Phase 1_ scenario 2

Meet at iClassroom to sign the contest form			
Local Expert	**Local Novice**	**Remote Expert**	**Remote Novice**
Sit on chair 2	Sit down on chair 3	From your office	From your office
Pick up the iPad and run the MiRTLE+ app	Pick up the iPad and run the iClassroom app	Run the MiRTLE+ app from your desktop	Run the MiRTLE+ app from your desktop
Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit
Choose: Local Expert **Team2** **Then click viClassrom**	Choose: Local Novice **Team1** **Then click viClassrom**	Choose: Remote Expert **Team1** **Then click viClassrom**	Choose: Remote Novice **Team2** **Then click viClassrom**
Join the just created iClassroom	Join the just created iClassroom	Click Create a new iClassroom	Join the just created iClassroom
You can point to the to see your opponent team	You can point to the to see your opponent team	**Right click on the mouse** to enable looking around **Escape key** from the keyboard to control events	**Right click on the mouse** to enable looking around **Escape key** from the keyboard to control events
Click on Press to talk for talking with all group	Click on Press to talk for talking with all group	Click on Press to talk for talking with all group	Click on Press to talk for talking with all group
Click on Start playing	Click on Start playing	Click on Start playing	Click on Start playing
Then, click on Register player name	Then, click on Register player name	Then, click on Register player name	Then, click on Register player name
Enter your username + e1 (e.g. **John e2**)	Enter your username + n1 (e.g. **John n1**)	Enter your username + e2 (e.g. **John e1**)	Enter your username + n2 (e.g. **John n2**)
Create a game session with a name **s2**	Wait for logging in instruction from the local expert **e2**	Wait for logging in instruction from the local expert **e2**	Wait for logging in instruction from the local expert **e2**
Ask through the mic **e1** to login on the game s2			
Then, ask through the mic **n2** to login on the game s2			
Then, ask through the mic **n1** to login on the game s2			
The target is to reach 300 point to win			
Expert can explain the rules ONLY before starting the game and between rounds	You can ask about the rules ONLY before starting the game or between rounds	Expert can explain the rules ONLY before starting the game and between rounds	You can ask about the rules ONLY before starting the game or between rounds
	If you do not know what to play, just guess and play.		If you do not know what to play, just guess and play.

Phase 1_ scenario 3

Meet at iClassroom to sign the contest form			
Local Novice	**Local Novice**	**Remote Expert**	**Remote Expert**
Sit on chair 3	Sit down on chair 4	From your office	From your office
Pick up the iPad and run the MiRTLE+ app	Pick up the iPad and run the iClassroom app	Run the MiRTLE+ app from your desktop	Run the MiRTLE+ app from your desktop
Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit
Choose: **Local** **Novice** **Team1** **Then click viClassrom**	Choose: **Local** **Novice** **Team2** **Then click viClassrom**	Choose: **Remote** **Expert** **Team1** **Then click viClassrom**	Choose: **Remote** **Expert** **Team2** **Then click viClassrom**
Join the just created iClassroom	Join the just created iClassroom	Click Create a new iClassroom	Join the just created iClassroom
You can point to the to see your opponent team	You can point to the to see your opponent team	**Right click on the mouse** to enable looking around **Escape key** from the keyboard to control events	**Right click on the mouse** to enable looking around **Escape key** from the keyboard to control events
Click on Press to talk for talking with all group	Click on Press to talk for talking with all group	Click on Press to talk for talking with all group	Click on Press to talk for talking with all group
Click on Start playing	Click on Start playing	Click on Start playing	Click on Start playing
Then, click on Register player name	Then, click on Register player name	Then, click on Register player name	Then, click on Register player name
Enter your username + n1 (e.g. **John n1**)	Enter your username + n2 (e.g. **John n2**)	Enter your username + e2 (e.g. **John e1**)	Enter your username + e2 (e.g. **John e2**)
Wait for logging in instruction from the local expert **e1**	Wait for logging in instruction from the local expert **e1**	Create a game session with a name **s3** Ask through the mic **e2** to login on the game s3 Then, ask through the mic **n1** to login on the game s3 Then, ask through the mic **n2** to login on the game s3	Wait for logging in instruction from the local expert **e1**
The target is to reach 300 point to win			
Expert can explain the rules ONLY before starting the game and between rounds	You can ask about the rules ONLY before starting the game or between rounds	Expert can explain the rules ONLY before starting the game and between rounds	You can ask about the rules ONLY before starting the game or between rounds
	If you do not know what to play, just guess and play.		If you do not know what to play, just guess and play.

Phase 1_ scenario 4

Meet at iClassroom to sign the contest form			
Local Expert	**Local Expert**	**Remote Novice**	**Remote Novice**
Sit on chair 1	Sit down on chair 2	From your office	From your office
Pick up the iPad and run the MiRTLE+ app	Pick up the iPad and run the iClassroom app	Run the MiRTLE+ app from your desktop	Run the MiRTLE+ app from your desktop
Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit
Choose: **Local** **Expert** **Team1** **Then click viClassrom**	Choose: **Local** **Expert** **Team2** **Then click viClassrom**	Choose: **Remote** **Novice** **Team1** **Then click viClassrom**	Choose: **Remote** **Novice** **Team2** **Then click viClassrom**
Join the just created iClassroom	Join the just created iClassroom	Click Create a new iClassroom	Join the just created iClassroom
You can point to the to see your opponent team	You can point to the to see your opponent team	**Right click on the mouse** to enable looking around **Escape key** from the keyboard to control events	**Right click on the mouse** to enable looking around **Escape key** from the keyboard to control events
Click on Press to talk for talking with all group	Click on Press to talk for talking with all group	Click on Press to talk for talking with all group	Click on Press to talk for talking with all group
Click on Start playing	Click on Start playing	Click on Start playing	Click on Start playing
Then, click on Register player name	Then, click on Register player name	Then, click on Register player name	Then, click on Register player name
Enter your username + e1 (e.g. **John e1**)	Enter your username + e2 (e.g. **John e2**)	Enter your username + n1 (e.g. **John n1**)	Enter your username + n2 (e.g. **John n2**)
Create a game session with a name **s4**	Wait for logging in instruction from the local expert **e1**	Wait for logging in instruction from the local expert **e1**	Wait for logging in instruction from the local expert **e1**
Ask through the mic **e2** to login on the game s4			
Then, ask through the mic **n1** to login on the game s4			
Then, ask through the mic **n2** to login on the game s4			
The target is to reach 300 point to win			
Expert can explain the rules ONLY before starting the game and between rounds	You can ask about the rules ONLY before starting the game or between rounds	Expert can explain the rules ONLY before starting the game and between rounds	You can ask about the rules ONLY before starting the game or between rounds
	If you do not know what to play, just guess and play.		If you do not know what to play, just guess and play.

Phase 2_ scenario 1

Meet at iClassroom to sign the contest form			
Remote Expert	**Remote Novice**	**Remote expert**	**Local novice**
From your office	From your office	From your office	Sit down on chair 3
Run MiRTLE+ app from your desktop	Run MiRTLE+ app from your desktop	Run MiRTLE+ app from your desktop	Run MiRTLE+ app from your desktop
Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit
Choose: Remote Expert **Team2** **Then click viClassrom**	Choose: Remote Novice **Team2** **Then click viClassrom**	Choose: Remote Expert **Team1** **Then click viClassrom**	Choose: Local Novice **Team1** **Then click viClassrom**
Join the just created iClassroom	Join the just created iClassroom	Click Create new iClassroom	Join the just created iClassroom
		Pick up the Oculus Rift glasses and put it on. Feel free to adjust it for your head	Pick up the Meta1 glasses and put it on. Feel free to adjust it for your head
Put on the headphones	Put on the headphones	Put on the headphones	Put on the headphones
Right click on the mouse to enable looking around **Click Escape key** from the keyboard to control the events	**Right click on the mouse** to enable looking around **Click Escape key** from the keyboard to control the events	**Move your head to look** around **Use your left mouse click to click on buttons and play on the game board**	**Use mouse or finger gesture to click on the events.** **Note:** finger gesturing is not accurately working with the game.
Click on Press to talk button for talking	Click on Press to talk button for talking	Click on Press to talk button for talking	Click on Press to talk button for talking – you can see this button when you look at your left side
Click on Start playing	Click on Start playing	Click on Start playing	You will see the game board just on your right side
Then, click on Register player name	Then, click on Register player name	Then, click on Register player name	Then, click on Register player name
Enter your username + e2 (e.g. **John e2**)	Enter your username + n2 (e.g. **John n2**)	Enter your username + e1 (e.g. **John e1**)	Enter your username + n1 (e.g. **John n1**)
Create a game session with a name **j1**	Wait for logging in instruction from the local expert **e2**	Wait for logging in instruction from the local expert **e2**	Wait for logging in instruction from the local expert **e2**
Ask through the mic **e1** to login on the game **j1**			
Then, ask through the mic **n2** to login on the game **j1**			
Then, ask through the mic **n1** to login on the game **j1**			
The target is to reach 300 point or above to win			
Expert can explain the rules ONLY before starting the game and between rounds	You can ask about things ONLY before starting the game or between rounds	Expert can explain the rules ONLY before starting the game and between rounds	You can ask about things ONLY before starting the game or between rounds
	If you do not know what to play, just guess and play. Then, ask your expert for correcting cards next rounds.		If you do not know what to play, just guess and play. Then, ask your expert for correcting cards next rounds.

Phase 2_ scenario 2

Meet at iClassroom to sign the contest form			
Remote Expert	**Remote Novice**	**Remote expert**	**Local novice**
From your office	From your office	From your office	Sit down on chair 3
Run MiRTLE+ app from your desktop	Run MiRTLE+ app from your desktop	Run MiRTLE+ app from your desktop	Run MiRTLE+ app from your desktop
Click Register button Only register: Username Password Gender Then click Submit	Click Register button Only register: Username Password Gender Then click Submit	Click Register button Only register: Username Password Gender Then click Submit	Click Register button Only register: Username Password Gender Then click Submit
Choose: Remote Expert **Team2** **Then click viClassrom**	Choose: Remote Novice **Team2** **Then click viClassrom**	Choose: Remote Expert **Team1** **Then click viClassrom**	Choose: Local Novice **Team1** **Then click viClassrom**
Join the just created iClassroom	Join the just created iClassroom	Click Create new iClassroom	Join the just created iClassroom
	Pick up the Oculus Rift glasses and put it on. Feel free to adjust it for your head		Pick up the Meta1 glasses and put it on. Feel free to adjust it for your head
Put on the headphones	Put on the headphones	Put on the headphones	Put on the headphones
Right click on the mouse to enable looking around **Click Escape key** from the keyboard to control the events	**Move your head to look** around **Use your left mouse click to click on buttons and play on the game board**	**Right click on the mouse** to enable looking around **Click Escape key** from the keyboard to control the events	**Use your mouse or finger gesture to click on the events.** **Note:** finger gesturing might not accurately work with the game.
Click on Press to talk button for talking	Click on Press to talk button for talking	Click on Press to talk button for talking	Click on Press to talk button for talking – you can see this button when you look at your left side
Click on Start playing	Click on Start playing	Click on Start playing	You will see the game board just on your right side
Then, click on Register player name	Then, click on Register player name	Then, click on Register player name	Then, click on Register player name
Enter your username + e2 (e.g. **John e2**)	Enter your username + n2 (e.g. **John n2**)	Enter your username + e1 (e.g. **John e1**)	Enter your username + n1 (e.g. **John n1**)
Create a game session with a name **j2**	Wait for logging in instruction from the local expert **e2**	Wait for logging in instruction from the local expert **e2**	Wait for logging in instruction from the local expert **e2**
Ask through the mic **e1** to login on the game **j2**			
Then, ask through the mic **n2** to login on the game **j2**			
Then, ask through the mic **n1** to login on the game **j2**			
The target is to reach 300 point or above to win			
Expert can explain the rules ONLY before starting the game and between rounds	You can ask about things ONLY before starting the game or between rounds	Expert can explain the rules ONLY before starting the game and between rounds	You can ask about things ONLY before starting the game or between rounds
	If you do not know what to play, just guess and play. Then, ask your expert for correcting cards next rounds.		If you do not know what to play, just guess and play. Then, ask your expert for correcting cards next rounds.

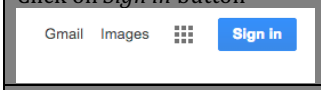
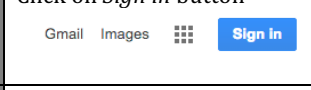
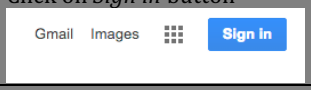
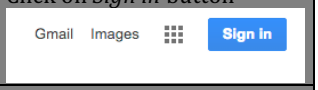
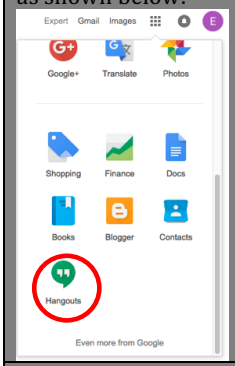
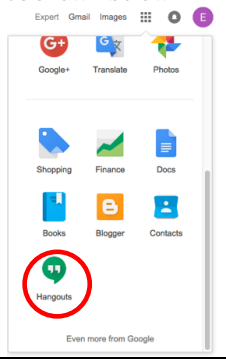
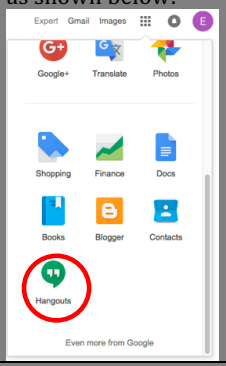
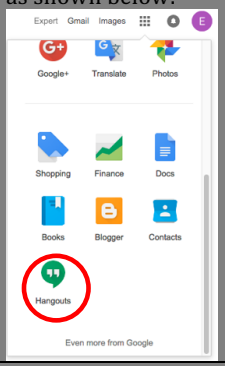
Phase 2_ scenario 3

Meet at iClassroom to sign the contest form			
Remote Expert	**Remote Novice**	**Remote Novice**	**Local Expert**
From your office	From your office	From your office	Sit down on chair 3
Run MiRTLE+ app from your desktop	Run MiRTLE+ app from your desktop	Run MiRTLE+ app from your desktop	Run MiRTLE+ app from your desktop
Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit	Click register button Only register: Username Password Gender Then click Submit
Choose: Remote Expert **Team2** **Then click viClassrom**	Choose: Remote Novice **Team2** **Then click viClassrom**	Choose: Remote Novice **Team1** **Then click viClassrom**	Choose: Local Expert **Team1** **Then click viClassrom**
Join the just created iClassroom	Join the just created iClassroom	Click Create new iClassroom	Join the just created iClassroom
		Pick up the Oculus Rift glasses and put it on. Feel free to adjust it for your head	Pick up the Meta1 glasses and put it on. Feel free to adjust it for your head
Put on the headphones	Put on the headphones	Put on the headphones	Put on the headphones
Right click on the mouse to enable looking around **Click Escape key** from the keyboard to control the events	**Right click on the mouse** to enable looking around **Click Escape key** from the keyboard to control the events	**Move your head to look** around **Use your left mouse click to click on buttons and play on the game board**	**Use mouse or finger gesture to click on the events.** **Note:** finger gesturing is not accurately working with the game.
Click on Press to talk button for talking	Click on Press to talk button for talking	Click on Press to talk button for talking	Click on Press to talk button for talking – you can see this button when you look at your left side
Click on Start playing	Click on Start playing	Click on Start playing	You will see the game board just on your right side
Then, click on Register player name	Then, click on Register player name	Then, click on Register player name	Then, click on Register player name
Enter your username + e2 (e.g. **John e2**)	Enter your username + n2 (e.g. **John n2**)	Enter your username + n1 (e.g. **John n1**)	Enter your username + e1 (e.g. **John e1**)
Create a game session with a name **j3**	Wait for logging in instruction from the remote expert **e2**	Wait for logging in instruction from the remote expert **e2**	Wait for logging in instruction from the remote expert **e2**
Ask through the mic **e1** to login on the game **j3**			
Then, ask through the mic **n2** to login on the game **j3**			
Then, ask through the mic **n1** to login on the game **j3**			
The target is to reach 300 point or above to win			
Expert can explain the rules ONLY before starting the game and between rounds	You can ask about things ONLY before starting the game or between rounds	You can ask about things ONLY before starting the game or between rounds	Expert can explain the rules ONLY before starting the game and between rounds
	If you do not know what to play, just guess and play. Then, ask your expert for correcting cards next rounds.	If you do not know what to play, just guess and play. Then, ask your expert for correcting cards next rounds.	

Phase 2_ scenario 4 - iPad

Meet at iClassroom to sign the contest form			
Local Novice	**Remote Expert**	**Remote Novice**	**Local Expert**
Sit down on chair 2	From your office	From your office	Sit down on chair 3
Run MiRTLE+ app from the provided iPad	Run MiRTLE+ app from your desktop	Run MiRTLE+ app from your desktop	Run MiRTLE+ app from your desktop
Click Register button Only register: Username Password Gender Then click Submit	Click Register button Only register: Username Password Gender Then click Submit	Click Register button Only register: Username Password Gender Then click Submit	Click Register button Only register: Username Password Gender Then click Submit
Choose: Local Novice **Team2** **Then click viClassrom**	Choose: Remote Expert **Team2** **Then click viClassrom**	Choose: Remote Novice **Team1** **Then click viClassrom**	Choose: Local Novice **Team1** **Then click viClassrom**
Join the just created iClassroom	Join the just created iClassroom	Click Create new iClassroom	Join the just created iClassroom
	Pick up the Oculus Rift glasses and put it on. Feel free to adjust it for your head		Pick up the Meta1 glasses and put it on. Feel free to adjust it for your head
Put on the headphones	Put on the headphones	Put on the headphones	Put on the headphones
Touch to click on buttons. **Point out to markers in order to see others in the environment**	**Move your head to look** around **Use your left mouse click to click on buttons and play on the game board**	**Right click on the mouse** to enable looking around **Click Escape key** from the keyboard to control the events	**Use your mouse or finger gesture to click on the buttons.** **Note:** finger gesturing might not accurately work with the game.
Click on Press to talk button for talking	Click on Press to talk button for talking	Click on Press to talk button for talking	Click on Press to talk button for talking – you can see this button when you look at your left side
Click on Start playing	Click on Start playing	Click on Start playing	You will see the game board just on your right side
Then, click on Register player name	Then, click on Register player name	Then, click on Register player name	Then, click on Register player name
Enter your username + n2 (e.g. **John n2**)	Enter your username + e2 (e.g. **John e2**)	Enter your username + n1 (e.g. **John n1**)	Enter your username + e1 (e.g. **John e1**)
Wait for logging in instruction from the remote expert **e2**	Create a game session with a name **j4** Ask through the mic **e1** to login on the game **j4** Then, ask through the mic **n2** to login on the game **j4** Then, ask through the mic **n1** to login on the game **j4**	Wait for logging in instruction from the remote expert **e2**	Wait for logging in instruction from the remote expert **e2**
The target is to reach 300 point or above to win			
You can ask about things ONLY before starting the game or between rounds	Expert can explain the rules ONLY before starting the game and between rounds	You can ask about things ONLY before starting the game or between rounds	Expert can explain the rules ONLY before starting the game and between rounds
If you do not know what to play, just guess and play. Then, ask your expert for correcting cards next rounds.		If you do not know what to play, just guess and play. Then, ask your expert for correcting cards next rounds.	

Experiment1 _ Web group

Meet Online using Google Hangouts			
Expert 1	**Expert 2**	**Novice 1**	**Novice 2**
Open Google page	Open Google page	Open Google page	Open Google page
Sign out from your google account if you are already logged in	Sign out from your google account if you are already logged in	Sign out from your google account if you are already logged in	Sign out from your google account if you are already logged in
Click on *Sign in* button 	Click on *Sign in* button 	Click on *Sign in* button 	Click on *Sign in* button 
Your user name: **iClassroom.e1** Password: **121231234**	Your user name: **iClassroom.e2** Password: **121231234**	Your user name: **iClassroom.n1** Password: **121231234**	Your user name: **iClassroom.n2** Password: **121231234**
Click on the shape Then, click on Hangouts app as shown below: 	Click on the shape Then, click on Hangouts app as shown below: 	Click on the shape Then, click on Hangouts app as shown below: 	Click on the shape Then, click on Hangouts app as shown below: 
Then you will be invited in a conversation by albashiri.ahmed@gmail.com **Note:** make sure that the conversation will carry on using only Voice.	Then you will be invited in a conversation by albashiri.ahmed@gmail.com **Note:** make sure that the conversation will carry on using only Voice.	Then you will be invited in a conversation by albashiri.ahmed@gmail.com **Note:** make sure that the conversation will carry on using only Voice.	Then you will be invited in a conversation by albashiri.ahmed@gmail.com **Note:** make sure that the conversation will carry on using only Voice.
Now open a new tab on your browser and enter: uno.arzahrani.sa	Now open a new tab on your browser and enter: uno.arzahrani.sa	Now open a new tab on your browser and enter: uno.arzahrani.sa	Now open a new tab on your browser and enter: uno.arzahrani.sa
Then, click on Register player name	Then, click on Register player name	Then, click on Register player name	Then, click on Register player name
Enter your username + e1 (e.g. **John e1**)	Enter your username + e2 (e.g. **John e2**)	Enter your username + n1 (e.g. **John n1**)	Enter your username + n2 (e.g. **John n2**)
Create a game session with a name **web1**	Wait for Joining the game session instructions from the local expert **e1**	Wait for Joining the game session instructions from the local expert **e1**	Wait for Joining the game session instructions from the local expert **e1**
Ask through the mic **e2** to login on the game **web1**			
Then, ask through the mic **n1** to login on the game **web1**			
Then, ask through the mic **n2** to login on the game **web1**			
The target is to reach 300 point to win – The results will be announced after each round by the experimenter			
Expert can explain the rules ONLY before starting the game and between rounds	You can ask about things ONLY before starting the game or between rounds	Expert can explain the rules ONLY before starting the game and between rounds	You can ask about things ONLY before starting the game or between rounds
	If you do not know what to play, just guess and play.		If you do not know what to play, just guess and play.

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