The Role of Augmented Reality and Virtual Reality in Digital Learning: Comparing Matching Task Performance

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Dedication

I would like to dedicate this work to my fiancé who has been my biggest motivator and supporter. I would also like to dedicate this thesis to my family whose love and support have helped me through school.

Abstract

This paper explores the potential uses of Augmented Reality and Virtual Reality in education and learning. It is important to understand if people learn differently in unique environments such as physical, digital, Augmented Reality, and Virtual Reality. Since a lot of learning occurs in the physical and digital realm, it is important to understand the role that Virtual Reality and Augmented Reality can have in education and learning. Exploring and quantifying learning in these different environments is challenging, so our research started out with basic memorization. To begin to understand this relation, we conducted a simple matching task in these environments collecting accuracy and completion time data. Results suggest that there is no significant difference between matching performance between environments. Results also showed that there may be a difference in user interfaces that environments provide, since some environments allowed user to complete the task faster than others. Additionally, we explored annotation and collaboration in Augmented and Virtual Environments. This study presents an initial exploration of user matching performance, collaboration, and annotation in these different media environments.

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1 Introduction

Historically, education is something that has primarily occurred in a traditional classroom. The internet brought a new way of thinking and sharing and has made it so that education can be done online through videos, presentations, and live streams. In recent years, there has been an increasing interest in deploying Augmented and Virtual environments to create unique educational settings [4]. In this paper, Augmented Reality is referred to as a form of reality which combines physical reality with digital holograms. This environment allows users to see their physical environment as well as digital holographic images. Virtual reality is a space where users have no optical interaction with real life. The user wears a headset and through specialized software and sensors is immersed in 360-degree views of simulated worlds [15]. A significant amount of literature has been published on Virtual and Augmented Reality's application in many different learning domains [4]. This literature will be discussed throughout this paper. Although many applications to conceptualize learning and training in Virtual Reality have been proposed, there has not been enough research conducted to fully understand and evidence to support the assumption that Virtual Reality can produce better learning [19]. The purpose of our research is to explore the potential uses and future scope of Augmented and Virtual Reality in an educational setting.

Development in Virtual and Augmented Reality has made continuous progress in the last few decades. Since the 1960's, more advanced hardware has become readily available, which has lead the rapid growth of Virtual and Augmented Reality to move from research settings to consumer devices [8]. Developments such as the Oculus Rift, Google Glass, and Pokémon Go have provided consumers with first-hand experiences with these environments.

Training and educational applications are often developed with these devices to help users learn new skills. The inventor of computer graphics and coiner of the term virtual reality, Ivan Sutherland, foresaw the possibility of these applications as early as 1963 [7]. These systems have been successful in scenarios such as vehicular operation and medial training [21]. These trainings and educational environments allow users to virtually learn before being put to the test in the real world. Virtual and Augmented Reality technology has also been used in domains such as education, engineering, and entertainment [8]. These technologies have been used by educators, playwrights, and movie makers [7]. Bailenson has also noted possibilities of trainings involving physical movements such as physical therapy and exercise. He further explains developments including trainings such as flight simulation, medical training, golfing, and choreography [5]. This shows how Virtual and Augmented Reality have been implemented into many different training and educational frameworks.

Although there have been many Virtual and Augmented Reality applications developed for training and education, the current state for research of education in these environments is still in its infancy [4]. Some research states that Augmented and Virtual Reality conceptual learning and training applications have been implemented, but there hasn't been significant evidence to support the notion that these systems can stimulate better learning [19]. Ragan states that while these environments could promote benefits for educational applications, little research has been formulated to show how they might improve learning [21]. A literature review concludes that the limitations of Virtual and Augmented environments include the difficulty of maintaining information, paying too much attention to virtual information, and the consideration of these systems as an intrusive technology [4]. Although some research states limitations and insufficient research in the area, other research presents benefits, and advantages of these technologies. Some research has concluded that interactive experiences can provide benefits for complex learning activities such as scientist concepts [20]. Additionally, some advantages in using this technology include learning gains, motivation, interaction, and collaboration [4]. A systematic literature review also found that Virtual and Augmented Reality have been effective in providing better learning performance, student motivation, student engagement, and positive attitudes [4]. Implementing Virtual and Augmented Reality into learning and education can be an exciting new endeavor, but it is important to understand the benefits, disadvantages, and effectiveness of this technology. By understanding these key elements, it is possible to explore the potential uses and future scope of this technology.

While exploring these potential uses of Virtual and Augmented Reality is important, it is also challenging to quantify learning. In educational studies, the ideal methods for measuring comprehension are not agreed upon [20]. Because of this obstacle, we decided to keep our research simple. Instead of attempting to measure learning in comprehension or concepts, we focused our research on memorization in these Virtual and Augmented environments. This research explores the similarities and differences of a user's performance during a matching task in different environments such as Virtual Reality, Augmented Reality, digital, and real. In this thesis, a digital environment refers to an environment such as a TV, computer, or phone that uses digital graphics to display content. Each one of these environments has its own affordances or capabilities. These abilities that each medium offer shape the nature of the content as well as determine the way the content is presented over the medium [26]. Because of this, it is important to understand if there are differences in learning between these mediums. In this research, we pose a single question: *Will there be performance differences across conditions?* To answer this question, we look at dependent variables such as completion time, trial number, and accuracy. This research has the potential to evolve the educational system - or at least display a better understanding of the role Virtual and Augmented Reality can have in an educational setting.

The rest of this document discusses background information about Virtual and Augmented Reality, our experiment, and results. Chapter 2 describes the complete background information necessary to understand Virtual and Augmented Reality and relevant technological equipment. This section also includes a Related Works and Future Works section that discusses the research that has been and will be done involving education and Virtual and Augmented Reality. Chapter 3 gives the implementation details of our experiment regarding a user's performance during a matching task in different environments. Chapter 4 discusses the results from the experiment as well as a brief discussion of limitations faced in this experiment. Chapter 5 concludes the document with a summary of the experiment, results, and future scope of this work. Finally, Appendix A contains snippets of code that were constructed during the development phase of the experiment.

2 Background

2.1 Background Information

Imagine watching a science demonstration that isn't physically there, but instead it is there virtually. In this scenario, an instructor and students can walk around the live demo physically and learn from this virtual environment. This can and is being done with the use of Virtual Reality (VR) and Augmented Reality (AR) equipment. For example, previous developed Virtual and Augmented Reality applications have been used to allow students to explore molecular structures, investigate Newtonian physics principles, and experiment with electrostatic fields [19]. These are just a few of the many different applications that have been developed specifically for these environments. Later sections will discuss a more in-depth overview of Virtual and Augmented Reality and the equipment utilized in creating these environments. Additionally, the use of Virtual and Augmented Reality in educational systems and relevant research regarding this topic will be discussed in future sections.

2.1.1 Virtual and Augmented Reality

Virtual Reality is a computer-generated environment that simulates physical presence in places in the real world or imagined worlds. One can think of virtual reality as an environment that a user is immersed in that can emulate senses such as vision and sound. While a user is physically in a real environment, virtual reality uses computer-generated graphics, video, and sounds to immerse a user in a completely different environment. Augmented Reality supplements the physical environment, by creating digital sensory input such as sound, video, and graphics. Much like Virtual Reality, Augmented Reality creates sensory input for the users. There is one key difference between the two environments; while Virtual Reality completely immerses the user into a virtual space, with no optical or visual interaction with the physical world, Augmented Reality utilizes the physical world by adding virtual information to it. One example of Augmented Reality is the smartphone application, Pokémon Go. In this game, there is a character that can move around a digital map that emulates the physical world. The application tracks the user's physical location and the only way to move the in-game character is by moving around physically. The game updates the location of the in-game character on the digital map to correlate where the user is in the physical world using GPS tracking. The goal of the game is to find creatures which are scattered all around this digital/physical space. In order to find these creatures, the user needs to physically move to those locations. Another environment, Augmented Virtuality, combines attributes of Virtual Reality and Augmented Reality. Augmented Virtuality achieves this by merging the real and virtual worlds. New environments and virtual visualizations are generated allowing physical and digital objects to co-exist and interact in real time [15]. The digital objects (holograms) are anchored to points in the physical space, which merge the virtual space with the physical space. Figure 2.1 shows this blended space. In this image, the user can simultaneously see the holographic menu and the physical world. The virtual menu can be anchored anywhere in the physical space, thus merging the virtual and physical environments together.

To understand the different environments, Milgram [14] introduces an environmental continuum based on four environments: Virtual Reality, Augmented Virtuality, Augmented Reality, and the real world. Figure 2.2 shows this continuum. As stated before, Virtual Reality serves as the complete immersion into an imagined world. In this world, sensory inputs like sound, and graphics are computer-generated to simulate a physical presence in that

Figure 2.1: The use of the HoloLens' holographic menu shows how the virtual world can be blended with the physical world.

world. In this environment user have no optical interaction with the real world and serves as one side of the continuum. On the other end of the continuum is the real-world environment. In this environment, users have no interactions with virtual inputs and only have a physical presence in their real-world environment. As the continuum displays, there are two hybrid environments that combine the virtual and real spaces: Augmented Virtuality and Augmented Reality. Augmented Reality sits closer to the real-world environment on the continuum and combines Virtual and real-world realities together. Augmented Reality supplements the real world by adding computer-generated input such as sound, video, or graphics. Augmented Virtuality brings real items such as doors and walls into the virtual spaces. It also acts as a supplement to the real world in the same way but has a key distinction from Augmented Reality. While the virtual content of Augmented Virtuality can be anchored to or interacted with the real-world objects, Augmented Reality does not infuse virtual content into real spaces; instead it only serves as an overlay and is not a part of the real world [22]. The important difference between Augmented Virtuality and Augmented Reality is distinguished in the environment in which the user interaction takes place. If this

Figure 2.2: A continuum of reality - fully virtual, real world, and hybrids involving both of those environments.

user interaction occurs in the real world, it is augmented reality, but if it occurs in the virtual world, it is considered augmented virtuality [24].

2.1.2 Augmented Reality Equipment

The birth of Augmented Reality was in 1968, when Ivan Sutherland created the first head-mounted display system [3]. Figure 2.3 shows this system. This system used computer-generated graphics to show three-dimensional skeletal models where only lines are shown. This system was designed to help helicopter pilots land at night and can track the user's eye and head movements [23]. This system was not fully virtual; it had transparency so that users could see the physical world as well. Figure 2.3 shows transparent spectacles in front of the user's eyes. The computer-generated imaging was projected onto those spectacles, and the user could also see the real world.

With a new race to develop new and better virtual and augmented reality equipment in the recent years, many companies have come out with new devices. [9] Some of these devices include: Google Glass, Microsoft HoloLens, Oculus Rift, and HTC VIVE.

Pictured in Figure 2.4, the Google Glass started the trend of wearable Augmented Reality [3]. The Google Glass uses computer-generated graphics to project holograms onto its display, which sits right above a user's eye. The holographic display makes it feel as though it is floating right in front of you [2]. While being connected to a smartphone with Bluetooth or Wi-Fi, the Google Glass can send messages, make phone calls, and give the user directions. It also utilizes a camera that allows its user to take pictures or record videos.

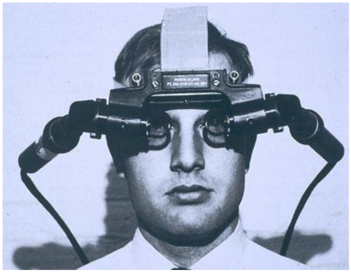

Figure 2.3: First head-mounted display system developed by Ivan Sutherland.

Figure 2.4: Google Glass - a wearable Augmented Reality device.

Figure 2.5: Microsoft HoloLens - allows holograms to interact with the physical world.

While the Google Glass can do a specific set of tasks, it lacked many other capabilities [25]. These shortcomings of the Google Glass have made this device be referred to as a ”humiliating stumble” [11].

Figure 2.6 shows that the HoloLens combines the look of a visor and glasses to create a head-mounted display. Instead of the user becoming fully immersed in a virtual environment, this device projects holograms onto the lenses, which allows the user to interact with both the virtual environment and the physical environment. This means that the HoloLens doesn’t cover the user’s entire field of vision; instead it displays holograms throughout the user’s physical surroundings based on where the user is looking. Additionally, the HoloLens also wields speakers, sensors, buttons, a camera, and a vent. The images projected in the HoloLens are seen on a narrow field. This allows floating app windows and three-dimensional models to be projected wherever the user would like them to be. The sensors and cameras analyze and map the user’s area including walls and objects and tracks the user’s location in relation to them. Virtual menus like browsers, apps, and settings can be anchored to physical walls. These virtual windows remain stationary as if they were physically connected to the real world [9].

Figure 2.6: HoloLens Visual

Figures 2.3, 2.4, and 2.5 show the evolution of Augmented Reality over time. In 1968, the first head-mounted display system (See Figure 2.3) was developed. At this time when Augmented Reality had first begun, this device could only display computer-generated skeletal models and track the user's eye and head movements. In 2013, 45 years after the birth of Augmented Reality, the Google Glass (See Figure 2.4) was able to project virtual holograms on a lens, which sits above the user's eye. This device acts as a camera and is also able to show the current time, menus, and web browsers. A few years later, in 2016, the HoloLens (See Figure 2.5) is introduced. This device uses sensors to learn the shape of the physical environment. With the understanding of the physical environment, the HoloLens can anchor its virtual holograms to objects in the physical world. Additionally, the sensors on the HoloLens can sense predefined hand gestures. These hand gestures are used to select, exit, move, and navigate the virtual holograms. Due to a smartphone revolution in 2009, the development of Augmented Reality escalated; since then, the expansion of smart wear technology has sparked another surge in the development of Augmented Reality [18].

Figure 2.7: Oculus Rift Visual

2.1.3 Virtual Reality Equipment

One Virtual Reality device - the Oculus Rift, fully immerses the user into a virtual reality environment by blocking out every optical interaction with the real world. The Oculus Rift was developed and manufactured by Oculus VR, who was eventually bought out by Facebook.

Figure 2.7 displays how the Oculus Rift uses a headset to mount the VR device on the user's head. The device is mounted in front of the user's eyes, so they only see the virtual environment. Immersion into this environment uses computer-generated graphics to trick the user into believing they are present in a non-physical world.

First, the Oculus Rift uses two visual inputs for the user to look into the device, much like looking into binoculars. The visual inputs display the game, demonstration, or other graphic that the device is currently projecting onto the high-resolution screen. The device uses two warped images on each half of the screen, which is like the way that binocular vision helps us perceive depth [16]. The Oculus Rift contains several sensors including a gyroscope, accelerometer, infrared sensors, and a camera which increases positional accuracy.

Figure 2.8: HTC VIVE Visual

Like the Oculus Rift, the HTC VIVE is a fully immersive Virtual Reality headset. The VIVE system consists of a headset, two controllers, and two laser emitter sensors. At a high level, the controllers and headset are photodiodes that indicate to the laser emitter units when they are hit by lasers [13]. These indications and the offset of time it took for the controllers and headset to be hit by the laser sensors allow for the position and orientation of them to be calculated and displayed. In many applications, the controller acts as a computer mouse. The controller can emit a virtual laser in the pointed direction of the controller, acting as a reticle to select virtual objects. The controller also has a button and a trigger that allows different actions to be taken when pressed. Like other technological equipment, the HTC VIVE tracking system needs to be calibrated frequently for the system to be able to recognize the size and orientation of the space.

2.2 Related Works

There have been numerous studies that have analyzed the affect Virtual and Augmented Reality have on a user's memory or learning. Studies conducted by Ragan et al. [19] found that memorization in a virtual environment can effectively be transferred to the real world. Their results also suggest that increasing immersion levels in virtual environments can improve memorization performance significantly compared to lower levels of immersion. Bailey et al. [6] concluded the contrary. In their study, they found that when completing a memory task in a virtual environment, higher levels of immersion lead to a decrease in a user's memory of that task in the physical world.

There has been research conducted in comparing learning tasks between different environments. In one study by Bailenson et al. [5], they manipulated one variable (media) to understand the difference in learning between digital video and virtual reality. In this experiment, users were taught specific moves in Tai Chi via one source of media. They concluded that the users learned better in virtual reality than in a video learning condition. In a follow-up experiment the researchers added a virtual mirror for the users to leverage the ability to see themselves in real time. In this study, it was also concluded that participants learned better in virtual reality than in the video. Research by Abbasi et al. [1], showed significant increases in critical thinking learning in augmented reality, when compared to physical lecture-style learning. During this experiment, the control group learning about chemical processes in a lecture-style environment, while the experimental group received a lecture along with a developed augmented reality application that also displayed the chemical process. After the lecture, the students were given a posttest where the experimental group's learning performance scored significantly higher than the control group. Maier et al.[12] hypothesized that their development of a 3D user interface of the structure of molecules could support better learning for students when compared to digital 2D structures. While this proposed method seems promising, their research did not test the effect of the different environments on students' learning.

There have also been research studies analyzing the effect of spatial presentation on user memory. In a study done by Ragan et al. [21], they found that spatial presentation in virtual reality significantly increased memory scores. In this virtual environment, participants used more visualization strategies during the memorization when background landmarks were shown in presentations. A follow-up study investigated if this increased performance can extend beyond memory. Though it seems promising, the study found that in critical thinking tasks, no performance improvements were gained from the spatial presentation method compared to a non-spatial presentation. In another study done by Ragan et al. [20], they tested the effect of navigational control on a user's learning. Participants were able to view information as an automated tour through the environment, or with their own manual controls. The study concluded that navigational type had no significant impact on learning outcomes.

Some studies have systematically reviewed other research regarding Augmented Reality's effect on learning. One such study is by Bacca et al. [4]. In this study, the researchers compiled 32 different studies between 2003 and 2013. Key findings from this research was advantages, limitations, and effectiveness of Augmented Reality. The authors concluded that advantages of augmented reality are learning gains, motivation, interactions, and collaboration. The limitations included difficulty maintaining information, paying too much attention to virtual information, and augmented reality being an intrusive technology. Many of the studies these authors looked at found that augmented reality has been effective for an improved learning performance, learning motivation, engagement and positive attitudes. While the results show limitations of the technology, augmented reality can still be utilized for improving students' learning performance and motivation to learn. Research by Poonsri [27] found that utilizing augmented reality in the classroom lead to enhanced learning and an increase in student motivation. These studies support the notion that augmented reality in the classroom can be utilized as an enhanced learning tool and increase students' motivation to learn.

In addition to memory and learning in virtual and augmented reality, it is also important to understand other potential uses of these technologies. Collaboration and annotation are two applications that these technologies can provide. Irlitti et al. [10] studied the challenges in collaborating and annotating in augmented reality. In this study, the authors explored different ways for users to collaborate and annotate in augmented environments. In a study done by Poupyrev et al. [17], the authors explored annotating in virtual environments. Their study found a way to transfer real world documents, to documents in the virtual world that can be written on. In their study they conclude that the potential of their application can go beyond notetaking and include collaboration.

Although these studies differentiate learning between environments, none have explored a user's matching task performance across digital, augmented, virtual, and physical environments. The current thesis tests user performance during a matching task across these four environments using a simple matching game. This study analyzes accuracy and completion time across environments to conclude matching task performance between the different environments. Our study also builds on the exploration of collaboration and annotation in virtual environments. This thesis explores different ways of annotating in different environments as well as collaborating with others to achieve a specific goal.

3 Implementation

3.1 Experiment 1

To test the potential of virtual and augmented reality in an educational setting, we created an exploratory experiment. This experiment begins to understand the relationship between a user's matching performance and the environment in which they are in. The importance of this type of research is to understand what type of capabilities certain environments have in an educational setting. By completing this type of experiment, it is also possible to begin to understand the advantages and limitations of virtual and augmented reality.

3.1.1 Overview

A between-subjects design was used to conduct an experiment to explore the relationship between a users' matching performance in different physical or virtual environments. The different environments included physical, digital, virtual and augmented, which are discussed in section 3.1.3. Each subject was randomly chosen to participate in only one of the four environments. The subject was then presented with a task which was consistent throughout all environments. As the subject completed their task, data was collected regarding timing and accuracy. After completion, the subjects completed a brief questionnaire measuring the amount of immersion and novelty of the experiment.

3.1.2 Sample

A sample of students was recruited from an undergraduate course at the University of Minnesota, Duluth. The final sample consisted of 91 students; 66 were women and 25 were men. The students' age ranged from 17-27 with an average age of 19.42.

3.1.3 Materials

Each of the four environments utilized different materials to complete the task.

The physical condition (See Figure 3.1) consisted of a chair for the subject to sit in, two tables for two different sets of 7 pairs of cards the rest on, and a phone to keep track of the data from the test subject. The cards were thickened with a foam layer to allow them to be more easily picked up.

The digital environment (See Figure 3.4) consisted of a 50-inch TV with touchscreen capabilities to run the experiment.

The Augmented Reality (See Figure 3.5) version of this experiment involved a Microsoft HoloLens, a Bluetooth keyboard, a Bluetooth clicker, and a physical table.

The Virtual Reality (See Figure 3.7) condition used an HTC VIVE (2 tracking stations, a controller, and a headset).

In each environment, a server was utilized to collect the data from the experiment. At the end of each trial, the End Method (See Appendix A.1.2) constructs a JSON object with information including trial number, subject ID, environment, attempts, and completion time. This JSON object is then sent to the server via an HTTP post. The server receives the request and stores the data for future use.

3.1.4 Design and Procedure

This study was approved through the IRB process at the University of Minnesota. Upon arrival, consent was acquired from the participant and the participant was then asked to fill out a survey detailing their age, gender, ACT score, GPA, academic, year in college, and college affiliation for data collection. The participant was then briefed on the task they would be undergoing and given a practice round before the experiment began.

Overview

The task to be completed was generally the same throughout all 4 environments. The user would be shown 14 cards (7 identical pairs) on top of a table, arranged in two rows of seven. The test subject would be given 15 seconds to memorize where the cards were in relations to each other, by looking at the card's faces. After the fifteen seconds, there would be a five second delay: In the physical condition, the participant was asked to close their eyes while the proctor(s) flipped the cards on their back and in the other conditions the cards would disappear for five seconds and then reappear facedown. The test subject was to then flip over cards – two at a time – attempting to match the identical pairs of cards. If the two cards they flipped over were the same they would leave them and move on, but if they were different, they would flip them both back over before attempting to flip over another two cards. Each trial would be complete after flipping over all matching pairs. Each participant completed a total of seven trials. The first trial was a practice round where the participant could ask questions during or after that trial before moving onto the actual trials. In the physical condition, the cards were shuffled by the proctor, and in the other conditions a button would pop up after a trial was complete. This button could be clicked by the participant to shuffle the cards and move onto the next trial. To keep the environments consistent, the participant was only allowed to use one of their hands to flip the cards. This

Figure 3.1: The real environment consists of a physical table and cards with a foam-core layer

outlines the general task between all environments. The differences in environments will be described next.

Physical Environment

In the physical condition (See Figure 3.1), the test subject sat down in between two physical tables. Each table had 14 cards (7 identical pairs) arranged in two rows of seven. The participant started the first trial on one table and once that trial was complete, turned around to the opposite table for the next trial (this was so that they wouldn't see the cards beforehand). Once the participant turned around and started memorizing the cards, the 15 second timer was started. While the participant was doing a trial on one table the cards were being randomly shuffled by a proctor on the other table in preparation for the next trial.

In this condition, a smartphone application was developed to keep track of the time and the number of pair flips, much like the other conditions did themselves. Figure 3.2. shows the user interface of the application. It has a trial number, timer, an input box, pair clicked button, stop button, and a reset button. In Figure 3.3, the trial number was used to show

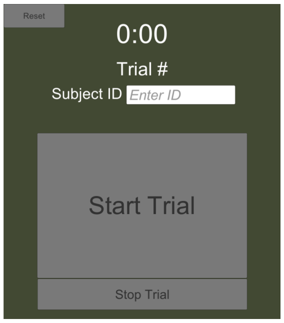

Figure 3.2: User interface of the application before the trial starts.

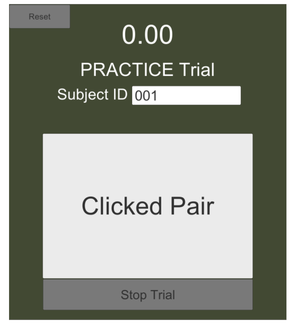

Figure 3.3: User interface of the application during the trial.

the experimenter which trial the participant was on. This kept an accurate count of the trial number. The timer was used to keep track of the initial 15 seconds the participant was able to preview the cards. It also was used throughout the experiment to track how long the experiment took to complete. The input box was used for the experimenter to input the participant's ID. The participant's ID was linked to the time the trial took to complete and number of pair flips it took to complete the task. The *pair clicked* button was used to indicate when a pair of two cards were flipped over (regardless of them being the same card). When this button was clicked it would indicate at what time on the timer a pair of cards were flipped over. A stop button was used to indicate that the experiment was complete, and all pairs of cards had been correctly flipped upward. Once the stop button was pressed, the participant's ID, the total time it took to complete, and each specific time a pair of cards were flipped over were compiled into a JSON object and sent across the network to a data collection server. Pressing this button would also increment the trial number counter for the next trial. This process was repeated for each trial of each participant. The time it took to complete the trial and each specific time a pair of cards were flipped over was used for analysis. The reset button was used to reset all the contents in the app. It reset the timer, trial number, and participant's ID to 0. This was used in between participant's to easily reset the contents for the next participant.

Figure 3.4: The digital environment consists of a 50-inch TV with PQ Labs touchscreen capabilities.

Digital Environment

The digital touchscreen condition (See Figure 3.4) was much like the physical condition. Instead of physical cards, the cards were digital images on a 50-inch TV and could be flipped over by tapping them on a PQ Labs touchscreen.

Augmented Reality Environment

The Augmented Reality condition (See Figure 3.5) was much different than the physical and digital conditions, since the cards were not touched or tapped. Instead of physical or digital cards, the cards were holograms in the Microsoft HoloLens and projected onto a physical table. In the HoloLens, the "cursor" is moved around by moving your head around – it essentially moves the cursor to the direction you are looking (See Figure 3.5). A clicker was given to the test subject to act as a mouse click for the cursor. The HoloLens allows

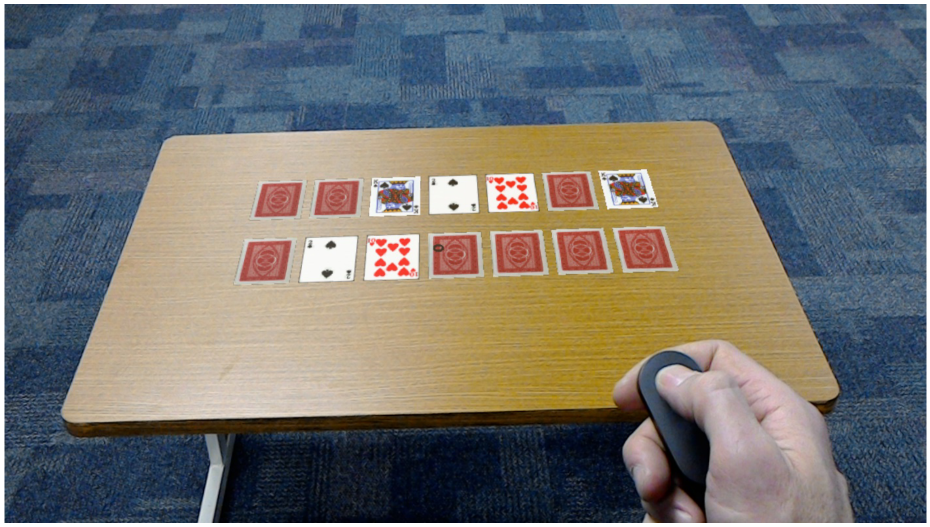

Figure 3.5: The holographic cards blend with the physical table to create a mixed reality environment.

users to use hand gestures to click, but we concluded that a clicker would easier be to understand. When clicked, the action would be performed on whatever object the cursor was on at the time of the click. In this condition, a training occurred before the actual experimentation. In this training, the test subject was tasked with using the HoloLens and clicker to click on blue boxes that were floating around the room (See Figure 3.6). The subject would move their head to move the cursor to one of the boxes, click the clicker, and the box would drop. This training occurred until the test subject felt comfortable using the HoloLens and clicker. This training was implemented solely to help the user understand how to use the equipment and select objects. Once comfortable, the test subject was told to turn around and click the single red box behind them. Once clicked, the playing cards would show up on the real table and the subject would start their first of seven trials.

Virtual Reality Environment

The Virtual Reality condition (See Figure 3.7) consisted of a fully immersive virtual reality. In this visual environment, the virtual space mimicked the space that the user was

Figure 3.6: The training helps familiarize participants with the equipment and selecting objects.

physically in, where the walls, tables, doors, and other objects in the virtual environment were similar and in a similar spot as the physical space (See Figures 3.8 and 3.9). Each subject wore a virtual reality headset to be immersed in this space. Each subject was also given a physical controller to use as their selector and this controller would be shown in their virtual environment and mimic the movements of it in the physical world. The controller had a physical trigger on it to act as a mouse click and a virtual laser pointer to act as the cursor. The same training as the HoloLens was implemented in this condition where the test subject was to align the laser pointer with blue blocks floating around the room and pull the trigger to have the blocks drop to the ground. This training was again used to familiarize the user with the technology before the experiment. This training also had a red block that would start the actual experiment when pushed. The test subject was told to click on this box to start the experiment.

3.1.5 Data Collection

Each participant was timed, and the time started when the test subject touched their first card and ended when they flipped over the last matching pair. Other data that was

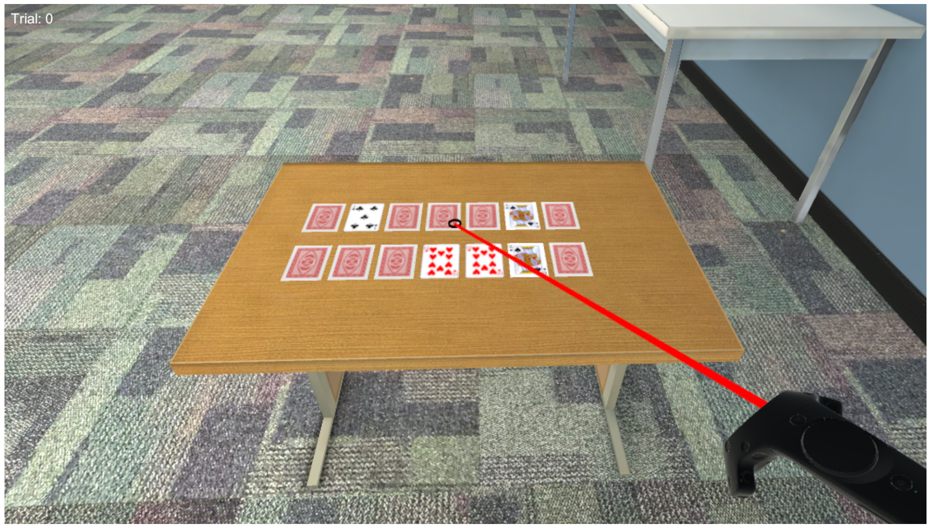

Figure 3.7: Virtual Reality Testing Visual

Figure 3.8: The physical lab used for the real and augmented reality conditions.

Figure 3.9: The virtual reality lab mimics the physical lab (3.8).

collected included: number of attempts (total number of correct/incorrect pairs they flipped up), each time at which they flipped over a pair, and a predetermined subject identification number. In the physical condition, a mobile application was used by the proctor to send this information to a server to collect. A timer was started by the proctor when the test subject touched the first card and the time was collected at each point when the test subject flipped over a second card in their correct/incorrect match. In the other versions, the application itself took care of all the data collection and sending it to the server. The application would automatically show the cards for 15 seconds, start the time when the test subject touched the first card, and collect the time at which the test subject flipped over each second card of a correct/incorrect pair. This data all got sent to a server for collection at the termination of each trial. The subject's identification number was manually entered into the mobile application for the physical condition and into the application itself for all other conditions.

3.2 Future Experiments

3.2.1 Collaboration

While the first experiment tested the accuracy and quickness of a single participant doing a simple matching task, future work could include collaboration in such environment. A simple experiment could be similarly set up with the matching task, but instead of a single participant, the experiment could utilize multiple participants. There are many different scenarios that could be explored with collaboration.

Collaboration can have potential uses in a virtual or augmented environment. Collaboration in these types of environments can allow multiple users to work together to reach a specific goal. Understanding how to collaborate in these environments can show the effect and potential uses for virtual and augmented reality in an educational setting.

One such case would be both participants having equal opportunity to look around with their own HoloLens and select cards with their own clicker. In this case, the two participants could be in the same room and communicate physically and verbally with each other to complete the task. In a different form of this task, the two participants could be in separate rooms and only be able to communicate with each other verbally. This type of experiment could show the effects of collaboration and single-person educational settings.

Understanding collaboration is important in showing how technology like augmented and virtual reality can be utilized. Much like matching in our first experiment, collaboration can be tested in all these environments to understand the capabilities each environment. Understanding this relationship can show the further potential of using virtual and augmented reality in an educational setting.

In another experiment, one user would act as a "master" and use the HoloLens and clicker to look around at the cards, but an additional "viewer" would be able to spectate the "master" and provide guidance. Much like the previous experiment, the viewer and master could be in the same room and communicate through physical and verbal cues. Alternatively, the viewer could be in a remote location and only communicate through verbal cues. This experiment would again display differences in communication as well as collaboration.

3.2.2 Exploring Gaze Direction

A more specific experiment could determine in which way a user can best use their gaze in the HoloLens to communicate to the other user what they're looking at. One problem foreseen in these experiments is each participant not knowing exactly what the other participant is looking at or referring to. We anticipate performing a pilot experiment to find the best way for two users to understand what each other is looking at.

In this experiment, the participants have a cursor on their own HoloLens to see what they are looking at in their own HoloLens. These cursors could be networked to each participants' HoloLens, so that each participant can see their own cursor as well as the other participant's cursor.

An alternate way of showing where a user is looking is using a highlighting mechanism to highlight where the other user is looking. If a user is looking at a specific card, that same card could have a glow or highlight in the other participant's HoloLens to know where the other participant is looking. The glow could change position as the participant looks at different objects.

Another way to help determine gaze is having a head avatar hologram that models the orientation of the user's head and gaze direction. As the participant tilts their head the avatar would also rotate. These avatars would be networked to both HoloLens so that each participant would know the direction the other participant is looking.

3.2.3 Collaboration in Augmented Reality

Like the initial matching task for a single participant, another matching task involving collaboration has been designed for the HoloLens. In this task, two individuals get to collaborate in the same physical space to complete the same matching task. In this task, both participants use their own HoloLens, HoloLens clicker, and are free to look around and click cards independently of one another.

In this Holographic environment, the two participants see and can click the same cards (See Figure 3.14). If one card is flipped over in one environment, that card is then flipped over in the other environment. This holographic environment emulates doing this task in the real world - all actions are seen by everyone.

Much like the initial matching task, each person has their own cursor that follows their head gaze. Although each participant can't see each other's cursor they can still understand which direction and where the other participant is looking. Each participant choses a holographic head avatar to represent themselves in the environment (See Figure 3.10). The head avatar represents where each participant is in the environment (See Figure 3.11). This avatar acts as the head of the other person and mimics the motions of the participant's head. If the participant tilts or moves their head, the avatar does the same thing. Each participant can see where the other participant is looking by looking at the direction of the head avatar (See Figure 3.12). Furthermore, if a participant looks at a card, that card glows in the other person's environment (See Figure 3.13). This helps each participant know what specific card the other participant is looking at (See Figure 3.14).

Figure 3.10: Different avatars to choose from to represent your head's position in the augmented environment.

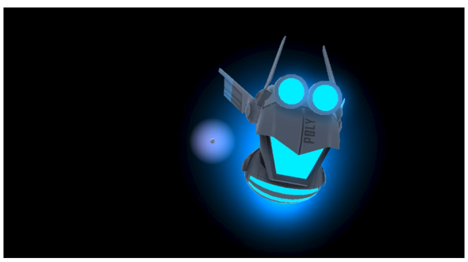

Figure 3.11: Example of a head avatar used by a participant.

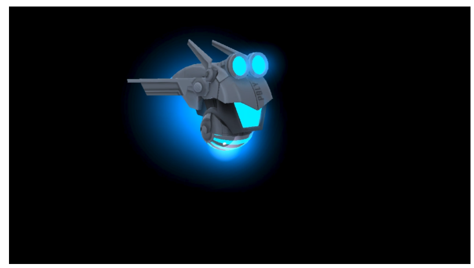

Figure 3.12: Displays how you can see the direction of another participant's gaze by looking at their avatar.

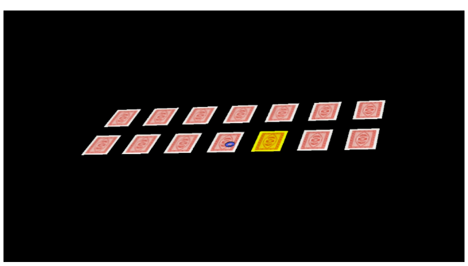

Figure 3.13: The card highlighted in yellow is where the other participant is currently looking.

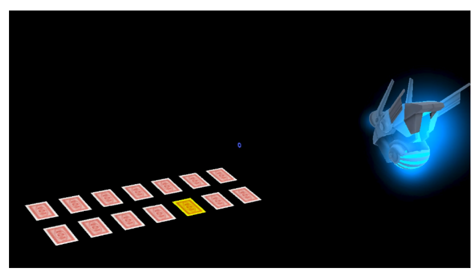

Figure 3.14: By looking at the highlighted card and the head avatar, it is clear to see where the other participant is looking.

HoloLens Networking

The HoloLens can display the locations and interact with another HoloLens through the network. When a user starts the application, they join a session which is hosted on a server.

This allows for multiple users to be in the same session. For one HoloLens to know what actions are being taken from the other HoloLens, they need to be given the correct information. This information is passed through networked messages created through the Custom Messages script (See Appendix A.1.5). These messages compile information regarding the action the user took and forwards it to the session they are in. For example, when a user clicks a card (See Appendix A.1.1), a network message is created including what user clicked the card and which card was clicked (See Appendix A.1.5). This message is then forwarded to every device in the session, for further action. When a device receives this message, the Remote Player Manager Script (See Appendix A.1.4) reads the message and takes appropriate action. For example, in the case of receiving a message regarding a card being flipped by another user, this script reads which card was flipped and flips it as well. This allows for each user in the session to see the same orientation of the cards. Like a user flipping a card, the cards that other avatars are looking at are updated through network messages. As a user looks at different cards, the GazeManager Script (See Appendix A.1.3) broadcasts a message containing which card they are looking at. When a device receives this message, the Remote Player Manager Script (See Appendix A.1.4) reads the message and highlights the card that was sent over the message. This allows for other users to know which cards are being looked at by other users in real time.

This experiment tests collaboration in such environments. Results may be compared to a similar experiment in the real world to understand how different environments affect collaboration. This could also be compared to the initial matching task to understand how collaboration affects accuracy or time completion.

3.2.4 Annotation Pilot Study

Just like collaboration, annotation in virtual and augmented environments can have potential uses in an educational setting. When in a virtual space, a user would be able to analyze a scientific structure and write down notes about their thoughts. This ability allows that same person or anyone else to view the notes that were taken. This can allow for more idea-sharing, understanding, or recollection. Understanding how annotation can be used in these environments and what effects it can have on memory or learning, can help present the potential of this technology in an educational setting.

During the initial experiment, it was hypothesized that annotating in the four different environments could play a role in the performance of the task since it would allow users to refer to the notes that they took. It was hypothesized that if a user was able to annotate or take down notes, they would be able to better remember where each card was. Because of this, the accuracy and time completion of each trial would show better performance.

To test our hypothesis, we started designing a pilot study like the initial experiment. This new design would allow the participants to take down notes in their environment.

Virtual Reality Skywriting Design

In the virtual reality environment, we designed a pilot study for participants to write in the air in 3D - also known as skywriting. In this method, a controller from the HTC VIVE was used as a writing utensil. This method of skywriting uses the location of the controller to begin writing in the three-dimensional space by using buttons to start and stop writing. When a button on the controller was clicked and held, the controller would begin skywriting at the location of the controller itself (See Figure 3.16). The controller would continue writing until the button was released.

One problem with skywriting in this type of environment was that it's not on a flat

Figure 3.15: A 3D skywritten note.

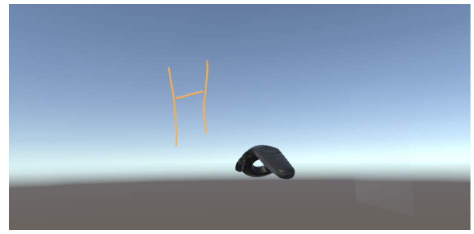

Figure 3.16: Skywriting with the VIVE controller.

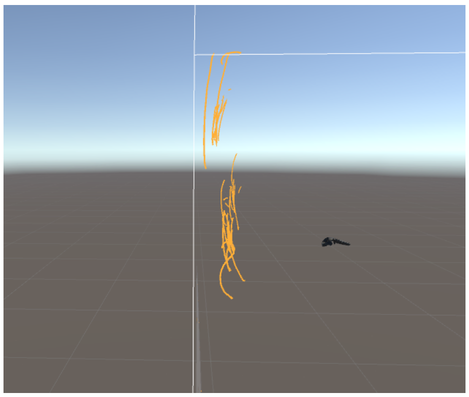

Figure 3.17: A sideview of a 3D skywritten note.

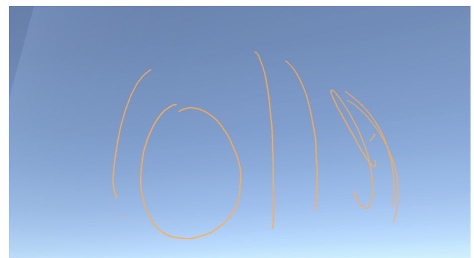

Figure 3.18: The back view of the phrase ”Hello!” shows how skywriting causes a bubble affect.

surface like writing on paper. While writing, VIVE controllers are also held in a different way than the tradition pen or pencil. While writing with a pen or pencil, fingers are primarily used to move the writing utensil. Conversely, when skywriting with a VIVE controller in this environment, the movement of the whole arm is utilized. The combination of not having a flat background to write against and utilizing the whole arm to write causes the writing to look curved and messy from a side view. Figure 3.17 shows a side view of Figure 3.15. The side view shows how the circular motion of the arm, causes the skywriting to become curved. Furthermore, Figure 3.17 shows how skywriting curves vertically as well as horizontally. Because of this, the skywriting starts forming a bubble or shell affect around the focal point. We concluded that skywriting might not be the best option for annotating in this type of environment.

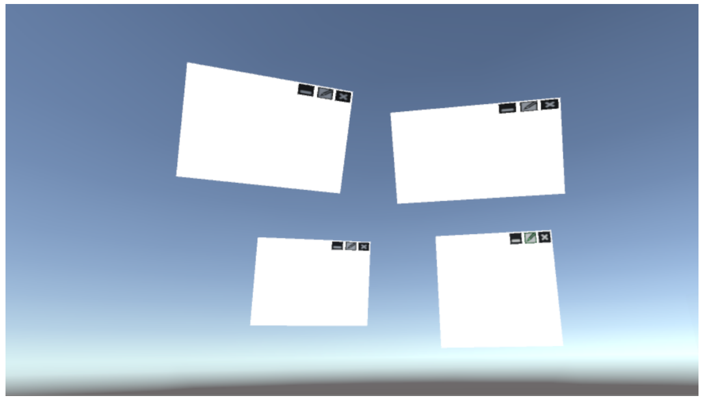

Figure 3.19: Multiple notepads being used to take down notes in the virtual environment.

Virtual Reality Notepad Design

To solve the problems with the skywriting design, a new pilot study was created. In this method, flat notepads were used to take notes in the environment (See Figure 3.19). The VIVE controller was used to create the notepads as well as write down notes. To create a notepad, a user would pull and hold the trigger of the controller and move the controller around. When the trigger was first pulled, the position of the controller acted as one corner of the notepad. As the controller moves around its position acts as the opposite corner of the notepad. When the trigger was released, the position of the notepad is set.

Once a notepad is in the environment, a user can take notes on it. Figure 3.20 shows when a controller points in the direction of a notepad a laser pointer emits from the end of the controller to the position on the notepad that it is pointed to. Once the controller is pointed at the notepad, a button on the controller can be clicked and held down to start writing on the notepad. As the button is held down and the controller is rotated, the notepad will be written on (See Figure 3.21). The writing stops once the button is released.

As seen in Figure 3.22 there are three little icons at the top right of each notepad: a minimize, edit, and exit button shown from left to right. Each button can be clicked with the controller's laser pointer. When clicked, the minimize button minimizes the notepad

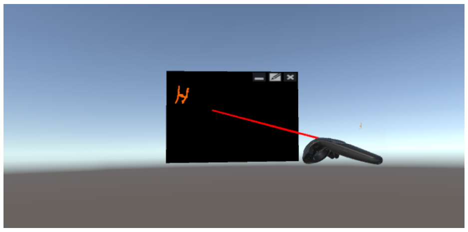

Figure 3.20: Laser pointer is emitted when a controller is pointed at a notepad.

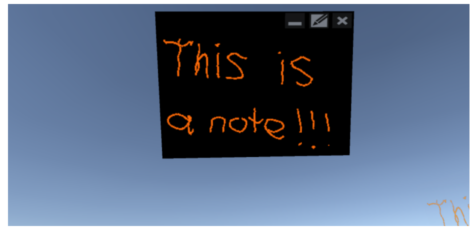

Figure 3.21: An annotation on a notepad written with the VIVE controller.

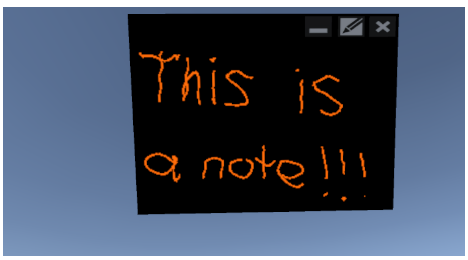

Figure 3.22: An annotated notepad in its maximized form.

Figure 3.23: An annotated notepad that has been minimized.

into a maximize button as shown in Figure 3.23. The maximize button can then be clicked to restore the original notepad into its normal state. This is useful for a user to make their environment less cluttered if there are too many notepads. When the edit icon is clicked, the notepad is not able to be written on. This saves the notepad in its current condition and can help prevent mistakes. The final button, the exit button, deletes the notepad from the environment. This is used in case a user finds a notepad irrelevant or useless and would like to get rid of it. These features aim to help user experience.

Writing on notepads in this manner poses a problem like skywriting. Although notepads don't require writing with the full arm, it still doesn't provide a natural way of writing. This method utilizes the wrist to write instead of the fingers in natural handwriting. Additionally, writing in this way still doesn't allow the user to rest their hand against something, which leads to messy and unclear writing. Because of this, we concluded that a user couldn't write legible and clear enough notes for this method to work to it's potential. We further concluded that the easiest and most consistent way for a user to annotate in this type of environment was using a writing utensil like a pen or pencil, and a flat surface to write against.

4 Results

The goal of this thesis work is to:

- Understand the relationship between a user's performance during a matching task and the environment they are in.
- Understand the advantages and limitations of virtual and augmented reality regarding user learning.

This section will discuss our approach to achieving these goals and evaluate the question this work revolves around.

Will there be performance differences across conditions?

4.0.1 Experiment 1 Results

One of the goals of this thesis is to understand how different environments can affect the matching task performance of a user. As mentioned in the previous section, to test this relationship, we created a simple matching game for participants to complete in four different environments: physical, digital, virtual reality and augmented reality. Dr. Edward Downs' statistical analysis displays the results of the experiment.

Figure 4.1 shows the average number of attempt's it took for participants to complete the matching task in relation to the environment they were in. ANOVA run across the four environments concludes that the number of attempts did not statistically differ by the type of environment ($F(87,3) = .61$).

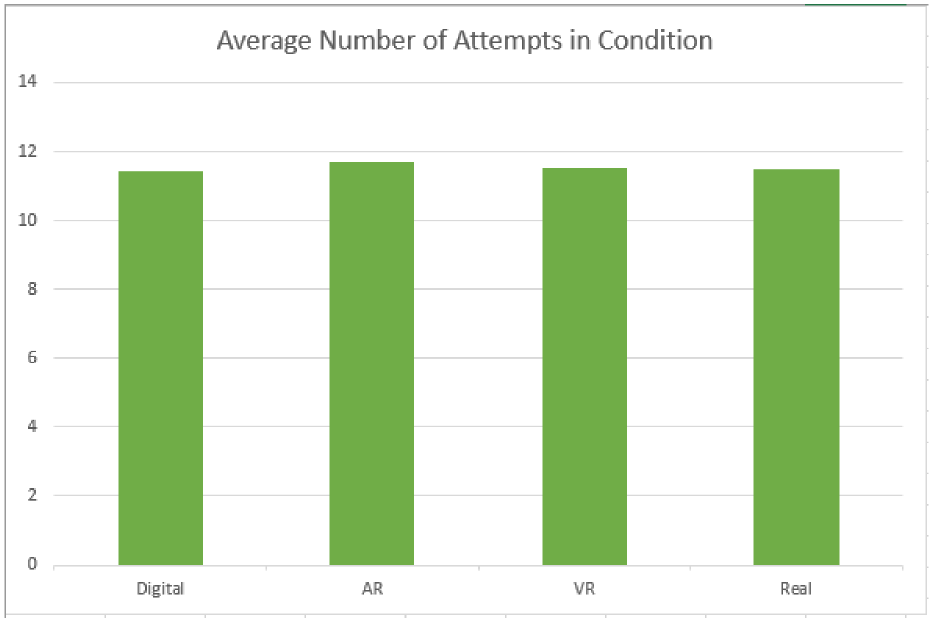

Figure 4.1: Average number of attempts in relation to condition.

Figure 4.2 shows the average time it took participants to complete the matching task in relation to the environment they were in. ANOVA run across the four environments concludes that the amount of time taken to complete the task statistically differed by the type of environment ($F(87,3 = 29.518)$, $p < .001$, partial eta = .504). The real and augmented reality conditions did not differ from each other regarding time completion but differed from the digital and virtual reality conditions ($p < .001$). Additionally, regarding time completion, the digital and virtual reality conditions did not differ from each other but differed from the real and augmented reality conditions ($p < .001$).

Figures 4.3, 4.4, 4.5, and 4.6 show the average completion time by trial number in each of the four conditions. Although trial 0 (test trial) is sometimes an outliner, our results show a general trend that as the participant completed more trials, the time it took for each participant to complete the task decreased as more trials were completed.

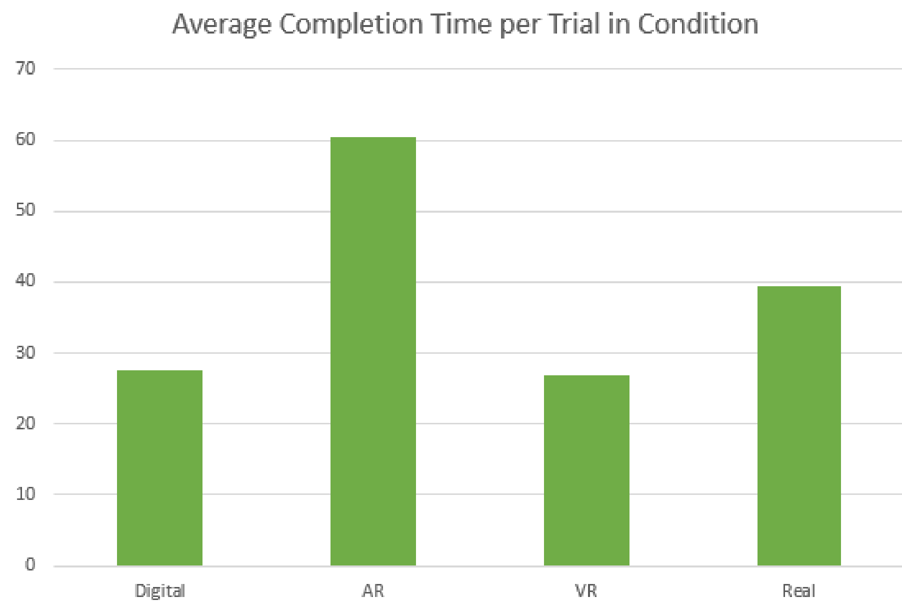

Figure 4.2: Average number of attempts in relation to condition.

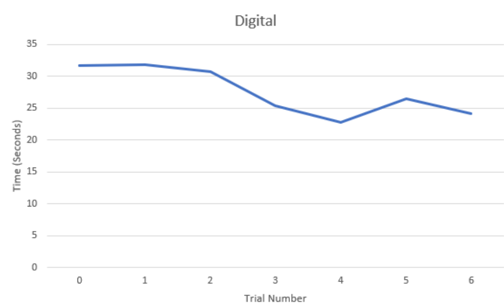

Figure 4.3: Average completion time by trial number in the digital environment.

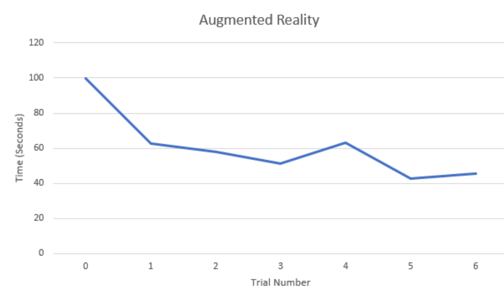

Figure 4.4: Average completion time by trial number in the Augmented Reality environment.

4.0.2 Discussion

The results from this study display the performance of its participants on a card-matching task in four different environments. Since there was no statistical difference between environments regarding how many attempts it took the participant to complete the matching task, it can be concluded that the environment a user is in has no effect on their matching task performance. Additionally, this helps answer our research question by showing

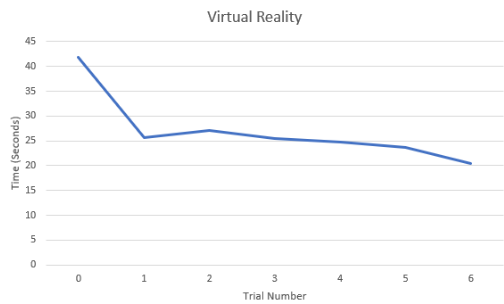

Figure 4.5: Average completion time by trial number in the Virtual Reality environment.

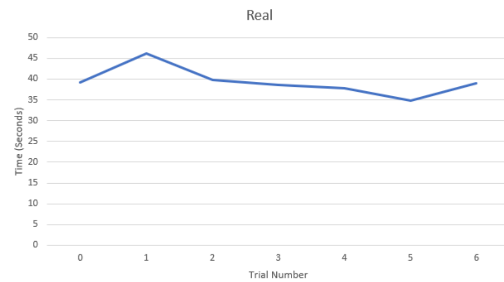

Figure 4.6: Average completion time by trial number in the real environment.

that no matter which condition a user is in, their matching task performance will not alter. Our results also show differences between environments in the time it takes a participant to complete the matching task. To try to understand this difference, it is discussed in Section 4.0.3.

Our results also show a general trend that as the participant completed more trials they had a decrease in the amount of time it took to complete the task. The reasoning behind this difference between trials is hard to justify. It could be explained by the user better-understanding the task, increased user memory, or even user comfortability doing the task.

4.0.3 Limitations

One possible explanation for the Augmented Reality condition taking the longest time to complete is systematic delay of the HoloLens clicker. This type of delay can occur when there is a significant time delay between the user's input (click, touch) and the response from the receiver (HoloLens, VIVE, TV). In the Augmented Reality, digital, and Virtual Reality conditions, there is an input device such as a wireless clicker, touchscreen device, or wireless controller, which could cause such delay. However, analysis shows that participants were able to complete the task in the Augmented Reality condition in similar ranges of time as the other conditions. This helps rule out any sort of systematic delay in our data.

Another possible explanation for the increase in time for the Augmented Reality condition could be the additional processing that the brain underwent in that condition. In other conditions, participants only needed to process one type of environment: single digital touchscreen, fully-immersive Virtual Reality, or real. In comparison, the augmented reality environment's task utilized the augmented environment and the real environment. This required the participant to process more than one environment concurrently and may have accounted for a for a time differential among the different environments. In addition, the Augmented Reality condition required the participant to use their gaze to control their cursor. As the participant would move their head, the holographic cursor would move along with it. This is much like moving a cursor with a mouse, but not something everyone would be experienced with. This lack of experience could have also lead to the increased amount of time it took to complete the experiment.

The real condition also took significantly longer than the Virtual Reality and touch screen. In this condition the participant had to physically flip over the cards. In comparison, in the Virtual Reality and touch screen conditions, the participants only had to tap or click on the cards. The motion of physically flipping over a card could have significantly increased the amount of time it took to complete the task when compared to just touching or clicking the cards.

5 Conclusions

Virtual and Augmented Reality have been used in many different settings such as entertainment, learning, and training. Although applications have been produced in these settings, it is important to understand if these technologies can foster better performance. This thesis mainly focused on understanding what role augmented and virtual reality play in an educational setting. While there were many studies that concluded these technologies bring better learning and increased educational motivation, other studies found limitations such as difficulty maintaining information and distracting information. The question proposed is whether these environments can foster better learning when compared to other environments such as the digital and physical world.

Trying to understand and quantify learning brings challenges. One challenge in educational studies is that methods for measuring comprehension are not agreed upon. This boundary poses problems when trying to understand the effects of different environments on learning. In our method, we simplified learning and instead tested a user's matching task performance in different environments. While the matching task was the same in different environments, each participant only completed the task in one environment. By only manipulating the environmental variable, we were able to understand the differences between the environments when it comes to matching.

In this thesis, we created a simple matching game for participants to complete in four different environments: physical, digital, virtual reality and augmented reality. Analyzing the results of the experiment, we found that environments have no effect on a user's ability to match different items. This is important in displaying the potential of utilizing virtual and augmented reality in an educational setting.

This thesis also explored areas such as collaboration and annotation in virtual and augmented reality. While the first experiment only included one participant, we developed another study to include two. Understanding how collaboration in these environments can affect matching has the potential to unlock further uses of this technology. In this follow up experiment, two participants can work together to complete the matching task. This type of study can show if collaboration is successful for matching tasks in these environments. This thesis also explored annotating in a three-dimensional space. It explored two options which utilized the VIVE controller: skywriting and writing on virtual notes. It was concluded that both methods were ineffective in providing the user with an adequate way of taking down notes in their virtual space. Further implementation could investigate different ways to provide the user a practical way to write down notes.

This work is a significant step towards understanding virtual and augmented reality's role in the education system. This research shows that although each environment offers different affordances, no environment offers significant advantages when it comes to a user's performance during a matching task. This concludes that these environments have the same capabilities as physical and digital environments when it comes to a user's matching abilities. This research also takes significant steps in understanding collaboration and annotation in these environments. With further research done in these areas, it is possible to understand the full potential of virtual and augmented reality.

A Appendix A

A.1 Code Snippets

This section contains code snippets that were used in the various applications developed for this thesis.

A.1.1 OnSelect Method for Selecting/Clicking a Card

The below code snippet shows the algorithm that follows a card being selected/clicked in the matching task.

```
//The image a card holds - the back of the card.
public Texture t1;
//The image a card holds - the front (face) of the card.
public Texture t2;
//A counter for te number of cards that were clicked.
public Counter c = new Counter();
//A counter for the number of correct pairs.
public Counter pairs = new Counter();
//Boolean for if te trial is complete.
public bool done = false;
//Boolean for if the user is currently viewing the cards.
public static bool CRRunning = false;
//Integer to hold how many pairs are currently flipped face up.
```

```
public static int numPairs;
//String to hold all the times a correct pair was flipped.
private static string flipTimes;

//Called if a card is selected (clicked).
void OnSelect() {
CustomMessages.Instance.SendFlippedCard(gameObject.transform.name);
 //Checks if the trial is over or if the participant is viewing the cards.
 if (!getEnd() && !CRRunning) {
  //Starts the trial timer if it's not yet started.
  if (CardsManager.timerStart == false) {
   CardsManager.timerStart = true;
  }
  //Increments the cards clicked counter.
  c.Count++;
  //Gets the mesh renderer (front or back image) of the card.
  MeshRenderer mesh_renderer = gameObject.GetComponent < MeshRenderer > ();
  //Ensures that it's either only pairs of cards or an even number of
      cards flipped face up.
  if (onlyPairs() || getCount() % 2 == 0) {
   //If the clicked card's image is the back of the card change it to the
      front of the card.
   if (mesh_renderer.material.mainTexture == t1) {
    mesh_renderer.material.mainTexture = t2;
    if (getCount() % 2 == 1) {
     temp1 = gameObject.GetComponent < NewTexture > ().t2;
    }
```

```
    //If an even number of cards are flipped face up, append the time the
       card was flipped to a string.
    else if (getCount() % 2 == 0) {
     temp2 = gameObject.GetComponent < NewTexture > ().t2;
     flipTimes += (CardsManager.timer + ", ");
     //If all pairs face up are matching pairs - increment the correct
        pairs counter.
     if (hasPair()) {
      numPairs++;
     }
     //If the number of correct pairs is 7, the trial is over.
     if (numPairs == 7) {
      end();
     }
    }
   }
   //Decrement the cards clicked counter.
   else {
    c.Count--;
   }
  }
  //There are an odd amount of cards face up or a mismatched pair of cards
     are face up.
  else {
   //If the selected face-up card doesn't have a matching card face up -
      flip it face down.
   if (!hasPair()) {
```

```
   mesh_renderer.material.mainTexture = t1;
  }
  //Decrement cards clicked counter since the cards are being flipped face-down.
  c.Count--;
 }
}
}
```

A.1.2 End Method for the Completion of a Trial

The below code snippet shows the algorithm that follows the completion of a trial and the data being sent to the server.

```
//Called when a trial finishes - sends trial data to a server.
void end() {
 //Activates a button for the participant to click. Upon pressing it, a new trial is started.
 shuffleButton.SetActive(true);
 //Stops the trial timer.
 CardsManager.timerStart = false;
 //Constructs a string with the trial data:
 //The current trial
 //The participant's ID
 //The condition (VR, AR, digital, real)
 //The number of correct or incorrect pairs flipped over
 //The time it took to complete the trial
 //Each time instance in which a pair was flipped over
```

```
string postData = "{\"trial\": \"" + CardsManager.trial + "\", \"subject\": \"" + IDInfo.instance.IDField.text.ToString() + "\", \"condition\": \"" + getScene() + "\", \"attempts\": \"" + (getCount() / 2).ToString() + "\", \"time\": \"" + CardsManager.timer.ToString() + "\", \"FlipPair Times\": \"" + flipTimes + "\" }";

//Initializes a Uri of the server.
Uri absoluteUri = new Uri("http://pekko.d.umn.edu:16081/api/exportData");

//Initializes a request to that server.
var request = (HttpWebRequest) WebRequest.Create(absoluteUri);
request.Method = "POST";
request.ContentLength = 0;
request.ContentType = "application/json; charset=utf-8";
var encoding = new UTF8Encoding();
var bytes = Encoding.GetEncoding("iso-8859-1").GetBytes(postData);
request.ContentLength = bytes.Length;

//Writes the request to the stream.
using(var writeStream = request.GetRequestStream()) {
  writeStream.Write(bytes, 0, bytes.Length);
 }
 //Gets the reponse from the server.
using(var response = (HttpWebResponse) request.GetResponse()) {
  var responseValue = string.Empty;

  if (response.StatusCode != HttpStatusCode.OK) {
```

```
    var message = String.Format("Request failed - received HTTP Error Code
        {0}", response.StatusCode);
    throw new ApplicationException(message);
   }
  }
  //Indicator that the trial has been complete.
 done = true;
}
```

A.1.3 GazeManager Script

The below code snippet shows how the system manages where the user is looking.

```
//GazeManager Script

//Called constantly in the Update() function to Update the Raycast, which
    identifies what objects (if any) are being hit by the user's gaze.
private void UpdateRaycast() {
 // Get the raycast hit information from Unity's physics system.
 RaycastHit hitInfo;
 Hit = Physics.Raycast(gazeOrigin,
  gazeDirection,
  out hitInfo,
  MaxGazeDistance,
  RaycastLayerMask);
 // Update the HitInfo property so other classes can use this hit
     information.
 HitInfo = hitInfo;
```

```
// If the Raycast hit a hologram.
if (Hit) {
 //If the hologram is a card - Highlight that card for other
    collaborators.
 if (hitInfo.transform.tag == "Card") {
  CustomMessages.Instance.SendHighlightedCard(hitInfo.transform.name);
 } else {
  CustomMessages.Instance.SendUnHighlightCards();
 }
 // If the raycast hits a hologram, set the position and normal to match
    the intersection point.
 Position = hitInfo.point;
 Normal = hitInfo.normal;
 lastHitDistance = hitInfo.distance;
} else {
 // If the raycast does not hit a hologram, default the position to last
    hit distance in front of the user, and the normal to face the user.
 Position = gazeOrigin + (gazeDirection * lastHitDistance);
 Normal = gazeDirection;
}
}
```

A.1.4 Remote Player Manager Script

The below code snippet shows how the system manages the network messages with the remote users.

```
//Remote Player Manager
```

```
//Manages the networking of a remote user.

//Initiatlizes network messages with their call-back functions.
void Start() {
 customMessages = CustomMessages.Instance;
 customMessages.MessageHandlers[CustomMessages.TestMessageID.HeadTransform]
    = this.UpdateHeadTransform;
 customMessages.MessageHandlers[CustomMessages.TestMessageID.HighlightedCard]
    = this.UpdateHighlightedCard;
 customMessages.MessageHandlers[CustomMessages.TestMessageID.UnhighlightCard]
    = this.UnHighlightCards;
 customMessages.MessageHandlers[CustomMessages.TestMessageID.CursorLoc] =
    this.UpdateCursorLoc;
 customMessages.MessageHandlers[CustomMessages.TestMessageID.UserAvatar] =
    this.UpdateUserAvatar;
 customMessages.MessageHandlers[CustomMessages.TestMessageID.FlippedCard]
    = this.UpdateCardFlipped;
 customMessages.MessageHandlers[CustomMessages.TestMessageID.UserHit] =
    this.ProcessUserHit;
 SharingSessionTracker.Instance.SessionJoined += Instance_SessionJoined;
 SharingSessionTracker.Instance.SessionLeft += Instance_SessionLeft;

 //Initializes an array of all the cards.
 if (cards == null) {
  cards = GameObject.FindGameObjectsWithTag("Card");
 }
}
```

```

//Function called to flip a card.
void UpdateCardFlipped(NetworkInMessage msg) {
 //Reads int from the network message.
 msg.ReadInt64();
 //Reads string from the network message.
 string cardString = msg.ReadString();
 //Finds the gameobject associated with the string.
 GameObject card = GameObject.Find(cardString);
 //Performs an OnSelect method on that card to flip it over.
 card.SendMessageUpwards("OnSelect2");
}

//Function called to highlight a card.
void UpdateHighlightedCard(NetworkInMessage msg) {
 //Reads int from the network message.
 msg.ReadInt64();
 //Reads string from the network message.
 string cardString = msg.ReadString();
 //Finds the gameobject associated with the string.
 GameObject card = GameObject.Find(cardString);
 //Retrieves mesh_renderer (image) that the card is currently showing.
 MeshRenderer mesh_renderer = card.transform.GetComponent < MeshRenderer >
    ();
 //Changes that image to a highlighted version.
 mesh_renderer.material = (Material) Resources.Load("Highlight",
    typeof(Material));
```

```
}

//Function called to unhighlight cards.
void UnHighlightCards(NetworkInMessage msg) {
 //Reads int from the network message.
 msg.ReadInt64();
 //Sets each highlighted card's image in the array equal to it's unhighlighted image.
 foreach(GameObject card in cards) {
  MeshRenderer mesh_renderer = card.transform.GetComponent < MeshRenderer > ();
  if (mesh_renderer.name == "Highlight") {
   mesh_renderer.material.mainTexture = card.GetComponent < NewTexture > ().t1;
  }
 }
}
```

A.1.5 CustomMessages Script

The below code snippet shows how the system creates network messages to send to all users in the networked session.

```
//CustomMessages Script

public class CustomMessages: Singleton < CustomMessages > {
 // Message enum containing our information bytes to share.
 public enum TestMessageID: byte {
```

```
HeadTransform = MessageID.UserMessageIDStart,
 UserAvatar,
 UserHit,
 ShootProjectile,
 FlippedCard,
 HighlightedCard,
 UnhighlightCard,
 CursorLoc,
 StageTransform,
 ResetStage,
 ExplodeTarget,
 Max
}

//Intializes the CustomMessage to send with the ID of the user.
 private NetworkOutMessage CreateMessage(byte MessageType) {
 NetworkOutMessage msg = serverConnection.CreateMessage(MessageType);
 msg.Write(MessageType);
 // Add the local userID so that the remote clients know whose message
    they are receiving
 msg.Write(localUserID);
 return msg;
}

//Creates a custom network message regarding which card was clicked on.
 public void SendFlippedCard(string card) {
 if (this.serverConnection != null &&
```

```
      this.serverConnection.IsConnected()) {
  // Create an outgoing network message to contain all the info we want
      to send.
  NetworkOutMessage msg = CreateMessage((byte) TestMessageID.FlippedCard);
  msg.Write(card);
  // Send the message as a broadcast, which will cause the server to
      forward it to all other users in the session.
  this.serverConnection.Broadcast(
   msg,
   MessagePriority.Immediate,
   MessageReliability.ReliableOrdered,
   MessageChannel.Avatar);
 }
}

//Creates a custom network message regarding which card is being viewed.
 public void SendHighlightedCard(string card) {
 if (this.serverConnection != null &&
      this.serverConnection.IsConnected()) {
  // Create an outgoing network message to contain all the info we want
      to send.
  NetworkOutMessage msg = CreateMessage((byte)
      TestMessageID.HighlightedCard);
  msg.Write(card);
  // Send the message as a broadcast, which will cause the server to
      forward it to all other users in the session.
  this.serverConnection.Broadcast(
```

```
    msg,
    MessagePriority.Immediate,
    MessageReliability.ReliableOrdered,
    MessageChannel.Avatar);
  }
 }
}
```

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