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Preparation of Human-Testing Experiment to Determine Key Features for Augmented Reality Applications to Succeed

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ABSTRACT

The evolution of mobile technology has placed augmented reality (AR) into the hands of previously inaccessible users. AR, which previously required specialized hardware devices, is now capable of running on most smartphones and tablets. Due to the abundance of AR capable devices, the medium is being explored by developers to create novel applications for various purposes, such as entertainment and education. With an ever-growing supply of AR applications, only a minority ever flourish. Through a thorough investigation of fields currently using AR, this paper hypothesizes the following are key features to a successful AR application: safety in the real world, visualization of information, affordances of virtual objects, and the use of a real-world environment. To design quality experiments proficient in evaluating effectiveness of the hypothesized features, a deep dive into exemplary experiment design and subsequent pitfalls was conducted. With this information, this paper presents the methodology of the proposed experiments that yield quantitative feedback for each feature, as well as safety and privacy forms for participants. Once conducted, these experiments will yield results that may impact the future of AR application development.

1 INTRODUCTION

The term "augmented reality" itself was coined in 1992 by Tom Caudell and David Mizell to refer to virtual images augmenting the visual field of the user with necessary information that will improve the performance of a current task (Caudell & Mizell, 1992). Since the creation of the first augmented reality (AR) device in 1968, AR has evolved with improvements to hardware size, weight, tracking, implementations, and more (Arth et al., 2015). AR has proven itself to be a novel medium through which a user may interact with the world. Current AR technologies range from head-mounted devices (HMD), such as HoloLens or Oculus Quest 2, to hand-held devices, such as most smartphones. As a result of the changes AR has gone through, AR has been explored for use in various fields, such as gaming, education, medical, and commercial use. While uses for AR expand multiple fields, its success in each of these fields varies greatly. For example, VR has achieved great success in gaming, while AR has seen less. Meanwhile, AR has flourished in medicine and has transformed the landscape of the field. Despite all the evolutions technology has gone through since 1968 and the vastly greater supply for AR devices, AR has not seen the same success as VR has. The reason for this is that AR has many inherent problems as a medium that VR does not suffer from. This lead Matt Dunleavy and Chris Dede to conclude in their 2014 study, AR in many ways is a solution looking for a problem (Dunleavy & Dede, 2014)." Due to the wide range of value that AR adds to fields, this paper aims to analyze the success and shortcomings of AR applications in these fields to unearth the key features that allow AR to achieve greatness. This will allow future developers of AR to make superior applications that are more likely to succeed. This paper hypothesizes that the following features are important to a strong AR application: safety in the real world, visualization of information, affordances of virtual objects, and the use of a real-world environment.

2 RELATED WORKS

Augmented reality (AR) has made impressive innovations and strides to become what it is today. In 1968, Ivan Sutherland is credited as the inventor of the first augmented reality system. This original system was an optical see-through head-mounted display (HMD) that used a mechanical and ultrasonic tracker that could handle six degrees of freedom (DOF) (Arth et al., 2015). Although this device was not portable, it predated the first mobile phone, which was created in 1973, and the first laptop, which was created in 1982 (Arth et al., 2015). Another key milestone in technology for AR is the invention of the Global Positioning System (GPS, officially known as "NAVSTAR-GPS") in December of 1993. GPS is still commonly used as a localization method for AR due to having an error range of just fifteen meters (Arth et al., 2015). Through technological advances over the decades, devices have become much more portable and powerful. While some hardware is designed specifically for AR, such as the Google Glass, most smartphones are also capable of running AR applications. There is an estimated over 810 million active AR users while there are only 16.44 million virtual reality (VR) devices available (Alsop, 2021, 2022)

Although VR and AR are often directly compared or used interchangeably in media, it is important to distinguish between the two mediums. As stated earlier, AR overlays virtual objects onto the real world to create environments. On the contrary, virtual reality environments are completely fabricated by their designers to appear precisely as needed. These virtual environments rely on complex virtual reality helmets or other means to update the user-visible space dynamically (Ivanova, 2018). The constantly updating surroundings of a user lead to an immersive experience where they will perceive and react to events occurring within the virtual world as if they were occurring in the real world (Ivanova, 2018). In contrast to VR, AR generally must be careful when approaching immersion. Pokémon Go, a popular AR mobile game, is an immersive game played in a normal environment. While users were immersed by the virtual elements in the real world, they have encountered numerous physical risks, most notably serious traffic accidents and muggings (Rauschnabel et al., 2017).

Physical hazards aside, VR applications enjoy a captive audience, meaning the user is not distracted by the outside world. AR does not share this property and has performed unexpectedly poorly in the game industry due to it. While there have been some successful AR games (Rauschnabel et al., 2017), most never leave the demonstration stage (Tan & Soh, 2011). There have been numerous studies looking into why AR games tend to fail, and how the ones that do succeed manage to achieve success (Kim, 2013; Liarokapis & Freitas, 2010; Ohshima et al., 1998; Perry, 2015; Rauschnabel et al., 2017; Schrier, 2006; Tan & Soh, 2011; Wetzel et al., 2008). These studies have found that designing games for an AR medium is generally more difficult than other platforms. To manufacture a well-received AR game, there are a plethora of human-computer interaction (HCI) design guidelines that should be adhered to. Listed below is a brief list of some elements outlined by “Guidelines for Designing Augmented Reality Games” (Wetzel et al., 2008).

Do not just convert

Do not stay digital

Use the real environment

Experiences first, technology second

Create sharable experiences

Use various social elements

Choose your tracking wisely

However, despite the above setbacks, augmented reality has found success in the following domains: education, medical, and industrial fields. Researchers have found that users generally reacted positively to using AR gamification to supplement education, such as in history, science, and language (Cai et al., 2014; Perry, 2015; Schrier, 2006). These studies found that students were positively motivated to learn and applied themselves more when AR games were used to supplement the lesson. One case study evaluated if learning the French language could be gamified using *Explorez*. *Explorez* uses game-based feedback tools such as experience points, badges, achievements, and progress bars to motivate students (Perry, 2015). By the end of the study, over 65% of the students continued past the minimum work required to receive an “A”. When students were asked to give their thoughts on *Explorez,* the reoccurring take-away was that the experience was more engaging than learning in the classroom only. Gamification of education has emphasized the importance for the user to have novel interactions with the AR device. The students enjoyed the novel method of interaction provided by augmented reality to keep their interest.

In the medical field, a plethora of AR projects have found immense success (Danciu et al., 2011; Juan et al., 2004; Moro et al., 2017; Yoon et al., 2018; Zhuang et al., 2021). Assisting in diagnosing diseases (Zhuang et al., 2021), fighting phobias (Juan et al., 2004), and telemedicine are just a sample of what augmented reality can do to enhance and improve medical practice. A key feature of AR that the medical field benefits from especially is projecting virtual images onto patients. Uses for this feature include improving precision during surgery, quickly identifying the location of veins in patients, and previewing potential outcomes of appearance altering surgery. Due to the inherent mortality rate of surgery, any means to reduce the risk of surgery is crucial. Before surgery is performed, head-mounted AR has been used to rehearse operations that draw from patient’s data for a personalized practice (Danciu et al., 2011). This training, along with AR imaging, allows surgeons to ensure an operation is as minimally invasive as possible. During surgery, surgeons can overlay incision points, diagrams, or any other necessary things to help with accuracy and precision. The use operating microscopes and endoscopes evolved to draw from the power of AR and are becoming more accurate and producing higher resolution images today. During surgery, a transparent heads-up display (HUD) can be used to present the patient’s vitals and other necessary information without having to look away from their current task. These innovations have led Marius Danciu to state in his survey of AR in health care “The use of AR in the medical field to provide better solutions to current problems than already existing solutions is infinite” (Danciu et al., 2011).

The last area reviewed in this paper that benefit from AR innovations is commercial and industrial. Companies, such as Amazon and IKEA, have integrated AR into their services to allow customers to preview a virtual to-scale products they are interested in buying. This feature has enabled retail companies to create novel interactions between brands and potential customers through an engaging experience that can broaden their interests in various products. (Raska & Richter, 2017; Romano et al., 2021). Several applications have risen in popularity due to allowing users to overlay filters and images on top of their smartphone cameras, such as Snapchat and TikTok. Utilizing these applications, users can view potential changes to their body, such as previewing tattoos, makeup, and even physical alterations to their face (Flavián et al., 2021). For industrial use, AR has proven successful in displaying potential product placement to management for approval and directing employees through visual guidance (Mourtzis et al., 2019). This use of AR has allowed warehouses to become more streamlined and efficient for workers and employers. Employees can scan a barcode to get directions to a particular product, take inventory efficiently, and much more (Mourtzis et al., 2019).

After reviewing the use of AR in the previously mentioned fields, it is possible to distill the following features of AR found to be most useful in their respective fields:

Table 1: AR features Found Most Useful in Their Respective Fields

Field Studied	Safety in the Real World	Visualization of Information	Affordances of Virtual Objects	Use of a Real-World Environment
Gaming	X	X	X	X
Education		X	X	X
Medical		X	X	X
Industrial & Commercial		X		X

3 METHODOLOGY

To determine the effectiveness of the hypothesized features, this paper will propose four experiments to evaluate each feature. To ensure high-quality experiments are put forth, a thorough exanimation of experiment design guidelines and pitfalls was performed. Whenever human participants participate in an experiment, physical safety is an immediate concern. While using a head-mounted AR device, such as the HoloLens 2, there are various potential physical risks involved. The most hindering and common negative side effect of AR is simulator sickness, which is a form of motion sickness. Simulator sickness symptoms include nausea, dizziness, spinning sensations, confusion, and drowsiness (Vovk et al., 2018). The difference between motion sickness and simulator sickness is that motion sickness is associated with gastrointestinal distress while the cause of simulator sickness is more visual. To combat simulator sickness, this paper recommends participants are preemptively made aware of potential symptoms and to withdraw from the experiment immediately if adverse symptoms are experienced. The most common adverse symptoms experienced for the HoloLens are eyestrain, followed by headache and general discomfort (Vovk et al., 2018). The next major risk to minimize and recognize is environmental hazards. AR applications have the potential to provide an immersive experience which may cause users to become unaware of their surroundings. This has led to users encountering numerous physical risks, most notably serious traffic accidents and muggings (Rauschnabel et al., 2017). To minimize environmental risks, this paper proposes ensuring the testing area is kept clear of potential hazards and participants are monitored carefully during testing.

Following safety concerns, ensuring the privacy of participants is paramount. Anecdotal media reports often claim that consumers under the age of 30 are generally less concerned about their privacy rights and would surrender them for improved access to online and mobile content (Hoofnagle et al., 2010). The reasoning behind these reports is that users under the age of 30 are generally more active in online social environments, and therefore more willing to trade privacy for interaction and entertainment. However, when asked, the users under 30 years old responded that their privacy is a major concern and have similar views to users over the age of 30 (Hoofnagle et al., 2010). To avoid infringing on participant's privacy, the AR applications will be designed to not collect personal information, personal data, or use facial recognition.

S. Pase describes AR as "a persuasive technology that raises significant ethical concerns" (Pase, 2012). Due to the novelty of AR and how a user interacts with the medium, AR can easily be filled with persuasive intentions that are unknown to a user. Another form of unethical persuasion easily accessible to AR comes in the form of explicit or implied threats of negative consequences, such as a punishment for failing. The experiments proposed will have no such elements as this study is searching for honest user feedback and has no intrinsic motivation to promote any of the features tested.

To obtain data for the outlined experiments, participants need to be recruited. This paper proposes picking participants from a subject pool along with accepting volunteers to partake in the tests. A subject pool is formally a pre-established group of individuals who have agreed to be contacted to participate in research studies. A benefit of using subject pools is that they are likely to be neutral actors on tests being conducted (Chiang et al., 2015). However, volunteers, are more likely to be more interested in the topic of the research, more educated, and have a greater need of approval. This can lead to volunteers with these attributes behaving differently than the general population (Rosnow & Rosenthal, 1976). Regardless of these pitfalls, volunteers will be a strong addition to the list of participants due to potential prior interest and knowledge of AR. If responses between the subject pool and volunteers is significant, then this paper suggests separating the two data sets and analyzing the reasons behind this outcome.

The purpose of the designed experiments is to evaluate the effectiveness of the following features for AR: safety in the real world, visualization of information, affordances of virtual objects, and the use of a real-world environment. For each previously listed feature, the experiment will be done with and without a given feature. The reason behind this decision is to allow each experiment to focus on the impact of a single feature's presence or absence. For the experiments put forth in this paper to yield meaningful results, determining what data to collect and how to collect it is imperative. The data these experiments will collect is quantitative feedback on the features listed previously that impact the users' enjoyment and their desire to continue to use an AR device. To obtain quantitative feedback from participants following the experiment, a simple Likert scale survey will be used. The reason behind this decision is that a Likert scale forces participants to specify their level of agreement with each statement on a questionnaire by selecting only one of several ordered alternative responses (Petrillo et al., 2011). Traditionally, the Likert scale poses five options to respondents, with the third option representing a neutral response. To avoid ambiguity offered by an odd number of Likert scale choices, this paper has chosen to use six choices. Having below five choices offers a risk of precision, while choices above six offer a minimal boost to precision (Simms et al., 2019). Another reason to avoid going over six choices is that more options can potentially confuse respondents who have difficulty perceiving differences between similarly worded options (Simms et al., 2019).

Each of the tests will be followed by a questionnaire with five questions. This allows each section to be easily scored and normalized for the effectiveness of a given feature. Due to each questionnaire totaling five questions with a Likert scale of zero to five, the minimum score is zero, while the maximum score is 25. To normalize a given test's score, divide the score by 25.

$$Tests = \{Safety, Visualization, Affordance, RealWorldObjects\}$$
$$\forall Tests; T\Delta = \left(\frac{SurveyResults}{25}\right)$$

$$TMag = \sqrt{(T\Delta_{Safety}{}^2 + T\Delta_{Visualization}{}^2 + T\Delta_{Affordance}{}^2 + T\Delta_{RealWorldObjects}{}^2)}$$

$$Normalized\ Vector\ of\ Feature\ Influence = \left(\frac{T\Delta_{Safety}}{TMag}, \frac{T\Delta_{Visualization}}{TMag}, \frac{T\Delta_{Affordance}}{TMag}, \frac{T\Delta_{RealWorldObjects}}{TMag}\right)$$

Equation 1: Calculation for the Normalized Vector of Feature Influence

The normalized vector of feature influence will allow the comparison of influence between the different features. The closer a value is to one within this vector will correspond to a feature which had significant impact on the user experience. Conversely, as a value approaches zero within this vector, the importance of the feature has little to no impact on the user experience.

4 DELIVERABLES

A major objective of this paper is to deliver all documentation for future experiments to be conducted. Listed in the appendix are the full-length design documents that include setup, steps to follow for a given experiment, and feedback questionnaires. After each experiment is completed, user feedback will be collected through the questionnaires. Three of the four experiments run two slightly different versions of their test, a first test without a feature, and a second test with the feature. The only exception is the second experiment, visualization of information, which has three tests. The first test includes no visualization of information, the second test includes gaze-controlled visualization of information, and the final test will include always on visualization of information. Below is a list of each feature being tested and an outline of their corresponding experiment.

4.1 Experiment 1 – Safety in the Real World

This experiment is meant to make users aware of the potential distractions an AR application may contain. Users will traverse a narrow virtual path that they must attempt to stay on. There will be pre-determined popups and notifications, like an immersive application might have, to distract users. To calculate extra results, the AR device will be tracking user position to calculate the deviation from the center of the path. It will also count the times the user received a warning for beginning to stray from the path and how many times they went off the path entirely. Once the first test is completed, repeat with the original path reflected across the XY axis and add safety features. If a user gets close to the edge of the virtual path, the AR device will have a red warning on the HUD to inform users if they are beginning to stray. Once a user has fully strayed off the path, the AR device will turn off all notifications and popups and direct the user back to the path. Once on the path again, the AR device will resume distractions.

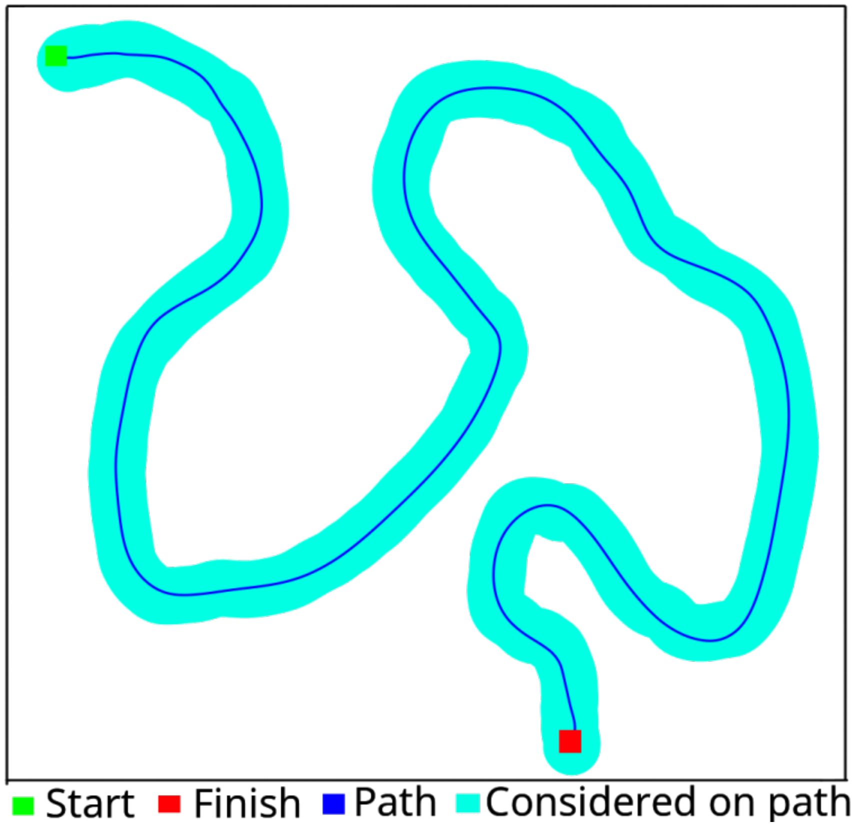

Figure 1: Example Path for Users to travel in Experiment 1

4.2 Experiment 2 – Visualization of Information

This experiment will have participants searching for a previously setup room for boxes that contain objects that they are instructed to find. The format in which objects are requested will vary from explicit real-world objects, such as a pencil, to descriptions of objects that participants will use to find the object in question. Each object in the room will be stored in a cardboard box with an attached paper on the front of the box. This paper will list the name, description, and uses for the object. Also on the paper is a QR code that, once scanned by the AR device, will display the information on the paper above the box as well. In the first test, users will not have the ability to scan the QR codes and must manually walk over to each box to find the objects asked of them. Once the first set of objects are found, test one is complete.

Before beginning test two, the location of each object must be scrambled so users may not rely upon prior knowledge. This version of the test will allow users to use gaze-control to scan the QR codes on the boxes to read the information instead. This version of the test should incentivize users to move more efficiently and should allow them an easier searching experience. Once completed, scramble the location of objects again to begin version three. This version of the test will not require users to scan the QR codes to display the information. Instead, the information will always be on display above the box. The reason behind the third test is to evaluate if having access to all information at once is beneficial to users. Record the time it takes participants for each version of the test.

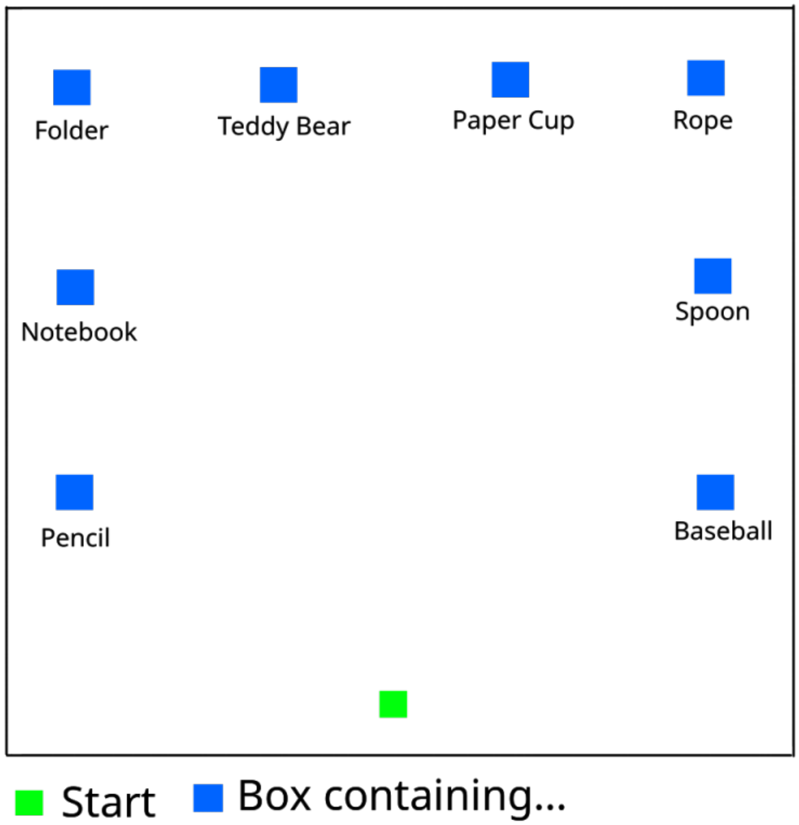

Figure 2: Example Room Layout for Experiment 2

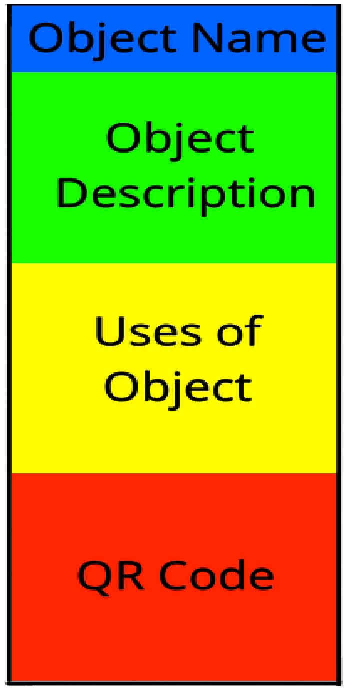

Figure 3: Example Layout for a Descriptive Paper for Each Box

4.3 Experiment 3 – Affordances of Virtual Objects

The third experiment focuses on how users interact with virtual objects. In this experiment, users will have the following virtual objects to interact with: a wheel, a pair of dice, and a 2x2 Rubik's Cube. Each virtual object is accompanied by a task that must be completed to move onto the next object. The reason behind choosing these objects is to emulate basic interactions, such as turning a wheel, semi-complex interactions, such as rolling dice, and complex interactions, such as solving a puzzle. The task associated with each virtual object is outlined below:

Wheel: Spin clockwise twice, and then counterclockwise thrice.

Dice: Roll the pair of dice until users roll a combined total of four, seven, and nine.

2x2 Rubik's Cube: Attempt to solve the 2x2 cube.

If a user is not able to solve it within five minutes and wants to stop, they may quit.

For the first version of this test, users will have to interact with virtual objects using virtual buttons. The wheel will have 2 buttons in front of it that, when held down, spin the wheel in the direction they display. In front of the dice's play space there will be a button to respawn the dice and automatically throw them in a random direction within the play space. The Rubik's cube will have a button associated with each action a user can make on the cube, such as turning the cube and rotating an edge. Once each task has been accomplished, the user will repeat the test with new changes. Virtual objects will now behave like they do in the real world. The wheel may be spun by pinch control, the dice may be picked up and tossed by the user, and the Rubik's cube may be controlled through pinch control as well.

4.4 Experiment 4 – Use of a real-world environment

The final experiment will have users interacting with the real-world environment to affect virtual objects. Users will use gaze control to guide a virtual character through a virtual maze. The first test will have virtual objects blocking the user's path that they must use pinch control to move an obstacle. Once the user has successfully guided the character out of the maze, the room setup will be changed to have real-world objects be obstacles in the virtual character's way. Using raytracing, the virtual character will not be able to move through these physical objects. Instead, participants will have to physically move the real-world objects to allow the character to progress through the maze to complete it.

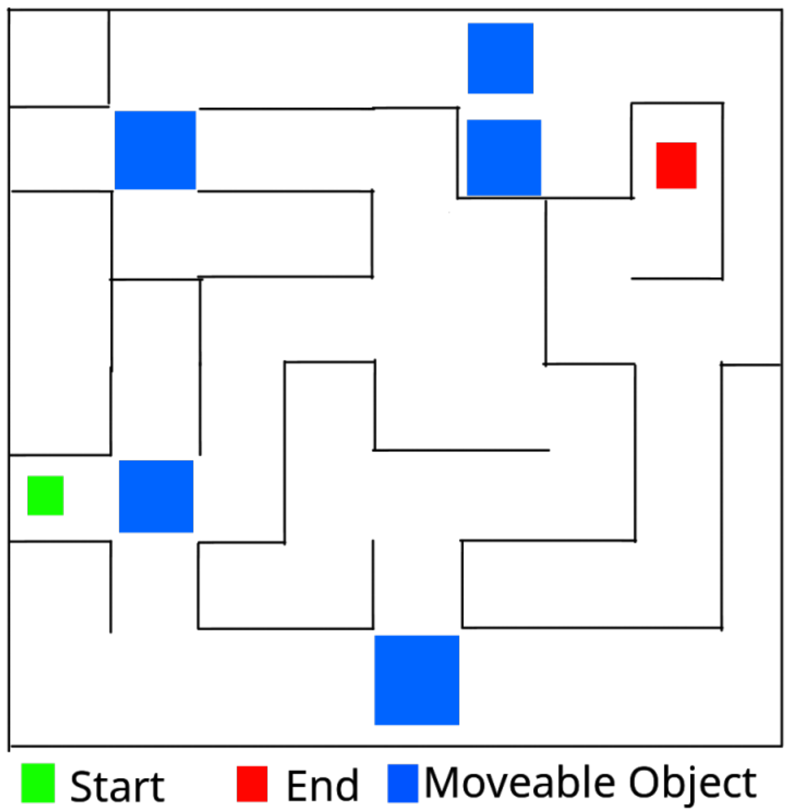

Figure 4: Example Maze Layout for Experiment 4

5 FUTURE WORK

The next logical step for this research is to run the above user-study and collect results. The experiments put forth have been carefully designed and will provide valuable insight into which features are most important for successful AR applications. Following the completion of the experiments, a thorough analysis of the data collected will yield results that can impact the future of AR application design. Should results show that the group of volunteers that participated in the experiment have a statistically significant difference in their responses compared to the subject pool, the groups should be analyzed separately. A follow-up research project would entail a thorough analysis to validate the correlation of the features presented in this paper and the success of mainstream AR applications.

Another facet of AR that should be further investigated is which AR features help promote positive social interaction between users. Several AR applications, such as Pokémon GO and *Explorez*, have proven the potential of using AR applications to encourage social engagement. Future experiments can be designed, like those put forth in this paper, and conducted to achieve a deeper understanding of how to design successful social based AR applications.

6 CONCLUSION

This paper performed an extensive literature review to unearth potential key features to improve the success of the AR application. Through this research, this paper concluded the following four features to be most impactful to a successful AR application: safety in the real world, visualization of information, affordances of virtual objects, and the use of the real-world environment. After establishing the previously mentioned AR features as worthy of further investigation, this paper performed a deep analysis on optimal experiment design with to put forth exceptional tests capable of evaluating the features. With this knowledge, this paper has offered advice on how to recruit a strong group of participants ensuring their physical safety and privacy in testing and data collection. The experiments put forth by this paper are designed to evaluate the effectiveness of each previously listed feature through simple AR applications that will include or exclude the chosen feature. This paper has also created safety waivers for participants and the surveys that will be used to gather data from the tests. Once performed, the results from the tests can be used to better understand how and why certain AR applications succeed, and others fail.

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