Empirical Research on Developing an Educational
Augmented Reality Authoring Tool

by

AYOUB GHARBI

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Abstract

This thesis studies the use of general-purpose Augmented Reality (AR) authoring tools in education and investigates the difficulties and drawbacks of such applications. While traditional education methods have proven their efficiency, academics constantly explore new ways to benefit from technology in education. Notwithstanding, elementary school teachers are tempted by the well-reputed success of incorporating AR in classrooms to enhance lessons, motivate students, keeping them focused, and so forth. They face, along with students, many challenges trying to adopt this technology to the curriculum.

We scrutinized the literature review to sort and analyze some of the difficulties of using general-purpose authoring tools in education and deduct heuristic and reflect on how to counter those difficulties to develop an education AR authoring tool.

We have developed and evaluated a prototype of an AR authoring tool made for education called CUAR (Carleton University Augmented Reality). Designed to provide elementary school teachers and students with a more practical and better experience than the current general-purpose tools. The 20 participants of the user study experimented with CUAR by performing multiple tasks designed for AR browsing and authorship and subjectively rated their usability experiences.

The results indicated that CUAR is generally easier to use and intuitive than another AR general-purpose solution in the user study. Moreover, presented clear insights that helped us draw a roadmap for future work toward perfecting this solution.

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CHAPTER 1: INTRODUCTION

1.1 RESEARCH BACKGROUND

We live in an era where computer processing power evolves rapidly, allowing it to be embedded in small computing devices and applications (Höllerer Tobias et al., 2004). Augmented reality (AR) is an evolving technology that has the potential to change humans' view of the real world (Jayiza, 2011). AR is described as a technology that improves the user's sensory experience of their surrounding environment with a computer-assisted contextual layer of information (Azuma Ronald T, 1997). Its systems incorporate virtual information within a person's real-world, information that can be perceived as one's existing surroundings (Höllerer Tobias et al., 2004).

In parallel, in the last ten years, smart mobile devices have become an essential part of current society's daily life (Kanaki et al., 2018); their high availability has led to widespread use across the population regardless of age. Even in some countries, the number of actively used phones surpasses its population (Billieux et al., 2015).

As the numbers and the processing power of smart mobile devices increases, technologists are able to equip them devices with AR and turn them into mobile augmented reality systems (MARS), which provide AR capabilities regardless of the user's location, and without the need for any special equipment (Höllerer Tobias et al., 2004).

It is commonly known that most students from elementary school to high school are already familiar with smartphones and tablets, having used them at home from an early age, which makes an easy transition from using the devices recreationally to using them for educational purposes. These devices are no longer confined to just sending messages

and receiving a call; now, they can offer many services and features ranging from access to the internet to reading emails to a variety of mobile applications with many functionalities (Vafa et al., 2017). In addition, mobile devices provide students with a wide range of non-functional features, like mobility, which allows them to work anywhere in the classroom or reinforce their skills at home, giving them the freedom to work at their own pace (Zhang et al., 2014). Moreover, a smartphone can be a perfect mobile AR System (MARS), a portable AR system in a compact form that a person can take everywhere. It uses a technology that can be moved from one place to another, like a desk-side computer and monitor or a laptop. On the other hand, a MARS requires a device with "mobile" characteristics like a smartphone, like a form factor which fits in a pocket, and it should be easy to operate (Craig and Alan B, 2013).

AR is a concept for displaying computer-generated content superimposed on top of real-world scenes that can enhance users' perception experiences (Bonsor, 2016). It utilizes image recognition or geo-localization techniques in the real environment as triggers. It uses this information to track the physical space and augment it with digital media content, such as 3D models, sound, images, videos, and texts. (Damiani et al., 2011.)

Azuma (Azuma Ronald T, 1997) published a survey that categorized possible areas that could use AR, such as aircraft, entertainment, robot path planning, manufacturing and repair, medicine, and many other fields. The academic field is no different and incorporates AR technology and many of its disciplines (Krevelen et al., 2010).

As research on AR technology has exponentially increased since 2011 (Akçayır et al., 2017), its potential in education has gained tremendous attention. Despite the proven success of current teaching methodologies, academic institutions are constantly looking for ways to improve students' cognitive capacities and learnability experience (Martín-Gutiérrez et al., 2015). Moreover, given the upraising significance of integrating technology into education, researchers are constantly looking for more practical technologies which would benefit and develop teaching methods despite the widely accepted old ones (Nincarean et al., 2013).

As an e-learning method, AR technology became widely deployed in a broad range of educational disciplines, on many levels, from elementary education to higher education (Akçayır et al., 2017). While some studies demonstrated that AR has a positive impact on teaching and continuous learning (Ibáñez et al., 2014), other studies showed that integrating AR with textbook material can support individual students' learning and can be leveraged to promote interest in STEM subjects (El Kouzi et al., 2019).

AR in education has been progressively recognized by researchers, resulting in a collection of AR tools that may be used in a variety of settings, including marketing, branding, and education (Billinghurst et al., 2015). These tools aim to support teachers with the ability to display virtual knowledge in a three-dimensional perspective (Da Silva et al., 2018). However, the applicability of the technology in teaching has remained minimal because of teachers' programming skills in developing AR experiences (Martin et al., 2011).

Building AR experiences requires programming skills, which is not necessarily among the skillset of the increasing numbers of interested users. This led to the

development of new AR mobile applications that serve as authoring tools, enabling users to build AR experiences without programming skills (Vert et al., 2017). These new applications also act like AR browsers for other users to view the created AR experiences. Augment, Layer, Wikitude, Junaio, and Aurasma count among the best-AR browsers in this industry (Jayiza, 2011).

1.2 PROBLEM STATEMENT AND SIGNIFICANCE

While AR opens the door for a state-of-the-art learning experience, it equally creates new education obstacles across a variety of domains as technological, pedagogical, and learning issues (Kera walla et al., 2006). Those issues create a barrier to incorporating AR into education, generating challenges for some teachers and students trying to implement it in classrooms.

According to Martin et al., (2011), the main reason for many of those challenges is the lack of AR authoring applications purposely designed for education, as most of the AR tools available are designed for broader applications such as tourism, marketing, navigation systems or healthcare (Billinghurst et al., 2015). The lack of research focused on teachers' and students' challenges, and the lack of AR authoring applications purposely designed for education might reduce the usage of this technology in classrooms, as well as educators' motivation and their trust in the benefits and positive impact of AR on the students.

The concluded problem is that there is not enough research that thoroughly looks into the fundamental challenges that students and teachers of an elementary school encounter when using a general-purpose AR authoring tool.

1.3 CONTRIBUTIONS

The main contributions of this thesis are:

1. Investigating AR authoring tools in education. Several papers highlight AR's success in education, but only a few mention its actual challenges and difficulties.
2. Guidelines informed by the literature review for developing an AR authoring tool dedicated to an elementary classroom using textbooks.
3. Developing a prototype AR authoring tool for education called CUAR based on the heuristics and evaluate its usability.

1.4 RESEARCH APPROACH

Our principal goal in this thesis is to investigate a solution to the flaws of using general-purpose AR authoring tools for education. Reviewing our related work, we defined the following research questions:

- Will an AR authoring tool specifically designed for education be more feasible, easier to use, and diminish technical problems likely to be encountered by students and teachers in the currently used general-purpose AR authoring tools?
- Will designing an AR authoring tool for education based on teachers/students probing result in an educational AR tool that does not require past AR experience to be used efficiently?

We based our research on the hypothesis that AR authoring tools specially designed for education offer better results in classrooms than general-purpose authoring tools in the current AR market regarding ease of use and usefulness. To evaluate our hypothesis, we

used a series of subjective measurements to appraise the ease of use of a prototype, which we designed for this thesis based on the difficulties found in the literature review.

We initially intended to conduct a usability study with elementary teachers and students conducting an observational method. However, due to a challenge highlighted in Chapter 5, we conducted a user study using two sets of participants who were general population users from Carleton University to represent elementary school students and pre-service teachers from Ottawa University to represent elementary school teachers. After exposing the first and the second set to a series of AR browsing and authoring tasks accordingly on CUAR, we used several usability questionnaires including SUS (Brooke John, 1996), USE (Lund Arnold M, 2001), SEQ (Wetzlinger et al., 20014) to collect quantitative data to measure the ease of use of the prototype and compare it to the ease of use of a general usage AR solution in order to pinpoint improvement areas.

We approached this research following these elements:

- 1) Listing the challenges and technical issues experienced by students and teachers while using AR authoring tools in classrooms.
- 2) Conducting a heuristics literature survey to generate our guidelines in developing an educational AR authoring tool.
- 3) Creating and evaluating a prototype AR authoring tool for education.

1.5 THESIS OVERVIEW

This section gives a summary of the structure of this thesis.

Chapter 2 (Related Work) examines existing literature and current mobile AR systems to precisely review existing challenges when used in education. This chapter allowed us to set up a framework for our research.

Chapter 3 (Educative AR Design Guidelines) explores and discusses design heuristics based on the literature review and sets some guidelines for developing AR educational tools.

Chapter 4 (CUAR Design and Development) discusses our approach to the design process and documents the development process of the CUAR prototype, showing the development details and technologies used in building it.

Chapter 5 (User Study) describes the evaluation methods, details about the experimental design and hypothesis, participant recruitment, and the study conduct.

Chapter 7 (Results and Discussion) presents and analyzes the preliminary usability testing results. We elaborate on data collection methods and present the data's statistical analysis, overall findings, and discussion.

Chapter 6 (Conclusion) brings the research to a close, summarizing the findings and drawing up a roadmap for future work.

CHAPTER 2: RELATED WORK

2.1 AUGMENTED REALITY IN EDUCATION

AR as a terminology has come a long way since it was used by Boeing researchers while exploring its usability to guide workers in creating wire harness bundles more efficiently (Caudell and Mizell, 1992). Nowadays, it is used to describe a direct or indirect view of a real physical world, whose elements are combined with virtual digital elements, to create a mixed reality in real-time; this is the main difference from virtual reality.

The AR interface does not reside as a distinct point between real and virtual but can be anywhere along the mixed reality continuum (Figure 1).

AR does not replace physical reality; it superimposes the computer data on the real world (Torres et al., 2019). The generated experience aims to enhance and complement the user's senses (hearing, touch, and sight) in the real world. AR provides various levels of immersion and interaction that can facilitate learning activities. Azuma (1997) presented the first survey in 1997, which classifies potential fields for the use of AR, such as manufacturing and repair, medicine, annotation and visualization, cultural expression, robot path planning, entertainment, aircraft, and military. Furthermore, it has been effectively integrated into many innovative applications such as advertising, shopping guides, gaming, travel guides, and edutainment (Papagiannakis et al., 2008).

The purpose of introducing mobile devices in education is not to replace traditional teaching methods, rather to enhance the educational process (Molnar, Andreea, 2014). The aim is to allow students to become active, stay engaged in their learning, and learn comprehensively by investigating and developing their creativity. Introducing mobile

devices in education also helps the instructors to offer a variety of teaching methods to meet the students' needs.

Bower et al. (2014) stated that the overlay of diverse digital media content on a real-world scene makes AR a cognitive reinforcement in understanding and performing tasks. Additionally, AR generates over-lasting experiences in students' memory compared with the resources from traditional books, digital slides, or even videos (Zhang et al. 2014).

Moreover, when digital content in 2D or 3D is overlaid on top of a physical world scene with a smartphone or a tablet, the user's attention is automatically drawn to the screen (Castellanos et al., 2014).

A variety of AR tools exist, but they differ in terms of functionality and complexity. Identifying the most appropriate one is dependent upon the desired outcome. The most complex tools, toolkits, libraries, and scripting frameworks such as ARcore, ARKit, ARtoolKit, and Vuforia SDK are produced for software developers. These enable the development of robust and tailored AR applications, but they require a high knowledge of programming languages like Java, C#, C++ or JavaScript.

On the other hand, educators will need access to some easy-to-use, zero-programming, no-cost authoring tools that can generate exciting and complex AR experiences that need to be available to many students at the same time. Fortunately, many zero-programming AR authoring tools are available for non-programming users. Mota et al., (2016) explored Wikitude, Layar, Metaio and Aurasma, and classified them as the most suitable apps that visualize 3D models, text, pictures, or videos as an augmented layer. These tools consist of simple and intuitive drag-and-drop interfaces for non-programmers, simplifying the procedure of creating AR scenes for non-programmers or AR expert

designers. They also offer other functionality such as image recognition and location-based features. In addition to allowing the user to edit the virtual objects' parameters such as position, size, rotation, or mark, they can be used and installed on mobile devices for free. However, there is some cost for accessing certain content sometimes. Mota et al., (2016) conducted a study of teachers' tools to create educational content for their subjects. The results showed that the distribution of the use of AR tools at various academic levels was: Aurasma (36.84%), Layar (10.53%), Aumentaty (10.53%), QR Code (10.53%) and the rest of applications like Quiver, colAR, Chromville, Augment totalled 5.26%.

In da Silva et al., (2018), the authors interviewed seven experienced teachers and two coordinators who use AR regularly in their class to understand the tools they are using and how, where, why they are using them. Results indicated that 44.4% use Aurasma, 22.2% use Element 4D, 22.2% use Quiver, and the remaining 11.1% mentioned Pokémon Go, Metaverse, 4D Mais, The Cell, Anatomy 4D, Treasure Hunt App, and Lifeliqe.

Aurasma, which became HP Reveal recently, is a mobile application that allows a user to take an image and create an overlay "Aura" on that image that can be triggered when hovering with the applications' camera on top of it. Auras can be as simple as a video and a link to a web page or as complex as a lifelike 3D animation (e.g., plays a video, takes the user to a website). Auras's production is done either through the web-based Aurasma Studio or using the Aurasma mobile application available for both Android and iOS. It does not require any programming skills. Every user can make a free account and create their own private or public Auras (Smith 2013).

Figure 1. Aura example in Aurasma application (eduwells.com)

2.2 AUGMENTED REALITY: TEACHERS' PERSPECTIVE

This section looks at the previous research exploring how soon-to-be-teachers will react to, find, use, and feel about AR authoring tools.

A study (Chookaew et al., 2017) examined how AR technology would motivate 136 pre-service teachers to construct teaching materials using a project-based learning methodology. The participants were students enrolled in the Instructional Material course at the University of Thailand. They were required to construct their own teaching materials in a structured manner with a higher-order thinking process. After going through all the steps and presenting their projects in the classroom, the participants responded to a questionnaire of nine questions designed to subjectively measure their motivation and confidence in using Aurasma to create their teaching materials. The questions were divided into three categories: Self-efficacy on the Instructional Material course, Instructional Material course, with AR Value and Achievement Goal on the Instructional Material course. The participants had to answer nine questions on a scale from 0 to 5 points, and the questions were:

1. "Whether the Instructional Material content is difficult or easy. I am sure that I can understand it."
2. "I am sure that I can do well on Instructional Material tests."
3. "I think that using AR for developing instructional material is important because I can apply it for teaching."
4. "In AR learning, I think it is important to participate in project-based learning."
5. "It is important to have the opportunity to satisfy my own curiosity when learning AR."
6. "I feel most fulfilled when I attain a good score in a course."
7. "I feel most fulfilled when I feel confident about the course."
8. "I feel most fulfilled when I can develop the instructional material."
9. "I feel most fulfilled when the teacher and other students accept my ideas."

Upon analyzing the results, this study revealed that the pre-service teachers had been highly motivated to use such technology to enhance their teaching process, making the study effective in measuring the pre-service teachers' motivation subjectively. However, it is missing any measurements to determine its usability and ease of use. A questionnaire embracing the rating scale could have helped determine how the participants rated the ease of using the Aurasma tool while creating their teaching material.

Moreover, it remains unclear how objectively significant teachers were in producing their informational materials using Aurasma because the application itself does not allow the teachers to record any metadata or student assessment notes in order to gauge students' performance and perception, which leaves a gap in the knowledge. The use of a third-party tool might be required.

Another study observed 62 students studying at the Computer Education and Instructional Technology Department and taking the hardware course (Ozdamli et al., 2017). The students were teacher candidates (pre-service teachers) who were, on average, 22 years old and planning to work at secondary schools after graduation. The researchers conducted an actual experiment splitting the PSTs: 30 students into experimental groups and 32 in the control group for a period of eight weeks. They used a reflective thinking approach to assess pre-service teachers' feelings and views regarding the hardware course's execution using the AR tool Aurasma and two measurements. The first measurement was the "reflective thinking scale" (Kember et al., 2000) assessment, based on the student's "online journals." A plug-in allows teachers to ask PSTs to reflect on the course content. The second measurement is a semi-structured interview prepared by the researchers with questions to identify the effectiveness and difficulties of AR Aurasma application for the experimental group only.

According to Basol Gulsah et al., 2013, the *reflective Thinking Scale (RTS)* is a 5-point Likert scale (ranging from 1 corresponding Agree Completely, 3 to Neutral, and 5 to Not Agree Completely), purposed to measure reflective thinking in habitual actions, understanding, reflecting and critical reflecting subscale levels.

Based on the reflective thinking scale, it can be said that supplementing reflective learning tasks with AR applications has a positive impact on users' reflective and critical reflective skills, which means users' ability to analyze their own experiences, developing the way they learn by asking probing questions. Critical reflective skills denote another level of reflection beyond what might or might not be covered by a reflective skill. It was also determined that students experienced a change in self-observation. They re-thought

certain behaviours they had adhered to before the study. For the interview results, for a total of 57 answers, 36.31% stated that AR enhances enjoyment, 22.80% stated that AR increases motivation, and 19.29% stated that AR increases interest and help in understanding; only 8.77% stated experiencing technical problems, and 3.50% stated that AR is an expensive technology.

The authors suggested that the AR applications developed for the hardware course were extremely useful, enjoyable, motivating, and intriguing and positively impacted reflective and critical reflective skills significantly. There was an increase in both of the groups' skills because the reflective learning tasks were implemented in both. However, it can be said that AR applications have a more significant impact on reflective learning skills.

PSTs learned the subject more comfortably and made no mistakes while assembling the hardware. For the technical difficulties using Aurasma, the authors claimed that any technical errors that occurred during the study process might have been caused by the use of differing types of devices.

In this study, the AR, through the application, proved its usefulness in increasing users' motivation and interest, enhancing the enjoyment, and boosting comprehension. Another strength of this study was subjectively assessing the user's post-experimental feedback in the form of interviews, which allowed each participant to describe any advantage or pain point of Aurasma freely. Five participants out of 57 experienced technical difficulties with Aurasma throughout the experiment. Those issues were mainly caused by the internet connection and light reflections hampering the process of scanning the markers with the camera. The lack of a more in-depth explanation and comprehensive

coverage of all the other technical difficulties are drawbacks. Still, knowing that Aurasma may cause difficulties depending on the user's device and its ability to connect to the internet is excellent input. However, light reflections preventing the markers' scan are more of an issue of the study's environment and settings.

It is worth mentioning that, compared to the total number of participants, only a few expressed their concerns about technical difficulties, which may be because the participants are coming from a more-or-less technological background as they are students of computer education and instructional background. This raises questions about teachers who do not necessarily have technical skills or do not come from a technical background.

Delello (Delello, Julie A., 2014) examined the usability of Aurasma by 31 pre-service teachers (PST) students enrolled in an undergraduate science methodology course in the College of Education in the US. Participants were introduced to AR and Aurasma and tasked to create science-based educative content. They were required to teach a primary school science class using the content. At the same time, participants had to reflect on the process of the experiment. For the data collection, researchers gathered the reflections, extracted AR-related information, and analyzed it. At the end of the study, it was concluded that Aurasma had an excellent appreciation from the PSTs. It was noticeable that AR positively impacted teaching experiences, including increased motivation and engagement, as well as teacher enthusiasm. They reported that Aurasma is simple to use and easy to understand. One PST said, "Not only is AR amazing, but it is also free and easy to do." However, 87% of the participants expressed a few usability problems. According to this study, there are many challenges in the integration of AR in education. This study

highlighted the fact that AR may be time-consuming. Teachers may not necessarily have the technical skills required to use such technology, or there may be a lack of infrastructure.

Slow internet connection or Wi-Fi issues were one of the main challenges that PSTs faced in this study. Their Wi-Fi was not able to sustainably support this technology. Additionally, the time factor was a concern to some participants. They stated that Aurasma would take too much time to train and familiarize themselves with it before preparing their teaching materials. Moreover, some participants considered the lack of devices while teaching the class as a technical challenge, suggesting that each student needs their own device instead of one for the entire class.

This study's advantage clarifies assumptions about teachers or pre-service teachers who do not come from a technical background and about their ease of usability while dealing with Aurasma. However, the lack of control and direction in terms of participants' feedback is a significant drawback. They could have been subjectively surveyed to extract more specific information related to Aurasma's use.

Delello et al., (2015) conducted a multidisciplinary study among Texas University students in the form of three cases across three majors. Case number 1 included 43 undergraduate students in the education discipline enrolled in a science methods course in the College of Education. The study aimed to determine the students' perceptions regarding the use of Aurasma and how AR enhances student learning.

Participants were tasked to use the Aurasma tool to develop an aura focused on elementary school-level scientific content, integrate it into a lesson plan, and then teach it to an elementary class during a field experience. For data collection, participants completed a pre-experience survey and a post-experience one. The first survey aimed to gather

participants' demographic information and technological background. The post-experience survey included five multiple-choice questions and three open-ended questions to ascertain the usability and student's attitudes after using the Aurasma tool. The pre-experience survey results showed that most of the students had a technological background but had never dealt with AR before. The post-experience survey conveyed that 77% of the participants rated their experience positively, and 82% of participants felt that the Aurasma platform enhanced their course learning experience. However, 48% stated that Aurasma was intimidating initially, and 45% commented that its use became more comfortable with practice.

Additionally, nine participants stated that creating an Aura with Aurasma is difficult. One of the challenges was the lack of capable devices since participants used their own. Another challenge was related to technical issues while creating a channel in the application (5%). A total of 15% of the participants encountered problems while uploading the Aura. One example was because a video from YouTube was too long. Some participants expressed their need for a better tool.

This particular case in this study revealed many pain points of the Aurasma application. The authors asked the participants detailed open-ended questions about their difficulties, which is a great strength of this study. The fact of not only focusing on the positive (how AR is useful and enhances learning) results as the other papers, but also exploring the negative points of its use was particularly insightful. However, the pre-service teachers' reflections (participants) and their students were not collected by the authors, which would have delivered further insights about the experience and usability.

According to Da Silva et al., (2018)'s findings, besides the lack of AR authoring tools, AR-experienced teachers also expressed their concerns about Aurasma's ease-of-use for not been intuitive and its demanding processing power.

2.3 AUGMENTED REALITY: STUDENTS PERSPECTIVE

2.3.1 Early childhood education (3–6 years old)

The adaptation of AR during early childhood education is increasing. Many examples illustrate the extent to how teachers are trying to integrate AR into the students' learning process. It has been implemented in many creative ways in the early educational stages to achieve a playful learning experience for the students. Based on the cognitive level of those students, Aurasma would not be a great fit. One particular AR tool which educators of young age students widely use is Quiver. Previously known as the colAR mix, it is an application that requires the user to download and print out various colouring pages from their website. Students decorate and colour the pages before scanning them with a mobile device through the application to generate an AR experience (Smith, Devin, 2016). Users can see a 3D virtual object generated and texture mapped with the same colours used to colour the pages within the AR scene. Models can also be interactive. For example, if the user touches a button on the screen while the animated AR dragon plays on the device, it makes the dragon breathe fire. Another example is the dancing girl model. Users can turn on and off the virtual radio button to make a 3D-generated girl dance (Clark, Dünser, 2012).

Torres et al., (2019) used the same methodology for an experiment, including students aged three to five years old. Data was collected was by interviewing the students after the experiment. The authors concluded that for children aged three to five, the scenes

generated by AR tools have a strong emotional impact and play a primary key in helping the children to remember ideas and concepts. Even though children at this age are considered to have a lower level of cognitive maturation or a shortage of using information communication tools, the experiment's conduct was not affected. All the students completed the experience as it was initially designed, no difficulties were observed, either technical or in the student's comprehension of the contiguity between physical reality and the models generated by the device in real-time, or of directing the camera towards the pages to reproduce the associated digital content.

In this segment, given the age of the students and the level of their cognitive maturation, it is very understandable to encounter a lack of research including this type of population and Aurasma at the same time, as their curriculum is not complex enough to require such an application to be utilized by the teachers. On the other hand, Quiver is appropriate and generated a positive experience for the students, proving once more that AR in education highly increases the interest, joy, and motivation for children aged three to five. Technical difficulties were almost non-existent due to the limitations of the application; it is highly controlled, and there is a tiny task that the teachers can do. In contrast to the Aurasma application, a lot can be done with it, making it suitable for a higher age group like the next segment of participant ages, who will be the main focus of this thesis.

2.3.2 Primary education (6–13 years old)

Primary school students have a higher cognitive maturation level than preschool students so that they can be exposed to more complex AR tools like Aurasma. On the other

hand, educators of those students will require more functionality in an AR tool to prepare a lesson suited to the students' age. This section looks at some previous work involving students in primary school using the Aurasma tool.

Tanner et al., (2014) conducted a study on a sixth-grade class of 19 students to experiment by building a Lego robot using a static paper manual versus an animated AR manual to make a difference. The students were aged 11 to 13 and were divided into two groups. Half of the class was the control group (using a paper-based manual). The other half was the experimental group (using the AR manual) created by the authors using the Aurasma application. During day 1 of the study, the participants had the process of the experiment explained to them. The authors explained to the participants what they would be asked to do and the associated vocabulary of the experiment giving them time to familiarize themselves with the LEGO parts that they would be building. On the second day, the students were grouped into four groups. Two groups had the same alligator LEGO robots, with paper-based and AR-based manuals. The two remaining groups had a bird LEGO robot. One group had a paper-based manual, and the other had an AR-based one. For data collection, the authors recorded the time students needed to build their robots, their error rate and subjective measurements in the form of questionnaires.

The study revealed that participants who used the animated manual comprehended the instructions better and built the robot faster than the participants who used the static manual. However, there is no significant difference in terms of the number of errors made by the students in both groups. Also, efficiency/self-sufficiency, engagement, satisfaction, ease of use and perceived learnability measurements were not significant.

The insignificance of the engagement was justified by the fact that WeDo robotics LEGO kits influenced the participants' high levels of excitement and engagement regardless of the type of the robot or manual. Moreover, despite the insignificance of the satisfaction measurement, it turned out that 90% of the surveyed participants preferred the paper-based manual over the reality augmented one with the Aurasma application and the iPad. This was due to the participants reporting that the application was hard to use and understand, affecting their enjoyment level.

According to the authors, Aurasma had some dysfunction, sometimes showing the wrong instructions for the students' steps to animate. The students also needed to hold the iPad over the manual and remain through the whole animation to watch it before putting the iPad down and performing the task as shown in the step. Moreover, the authors indicated that in most cases, students needed to stand up entirely from their chairs to scan the whole page of the manual with the iPad's camera, which generated significant discomfort to the students compared to those who used the paper-based static manual.

The experiment conducted in this paper correlates to this study's motivation, which determines if AR increases students' comprehension, thus making them more effective in performing the tasks. Moreover, as in the previous research, AR delivered that as expected, except that the enjoyment of the participants was described as lower because of two main reasons. The first reason was that the “challenge effect” of building a Lego Robot using a paper manual was eliminated by the animated manual displaying how to do the steps straightforwardly, thus killing the challenge of figuring it out. Furthermore, the second reason was because of the technical difficulties and some complaints about the ease of use

of Aurasma by some participants. This paper's disadvantage is the lack of detail about the usability issues, claimed to be several, yet only describing two examples.

2.3.3 High School Students

Secondary school students are aged 14 to 18. At this age, students are capable, due to their cognitive skills, of easily interacting with technology and accurately describing their experience while doing so.

In this regard, authors Hsu et al., (2015) conducted a study including two high school classes totalling 84 students and an AR teaching approach. One class served as a control group using traditional didactic instructions. The other class received the same content as the experimental group via tablets using pictures as markers and Aurasma as AR to overlay some teaching material's videos. The experiment lasted four weeks at two hours a week. Its goal was to evaluate the effectiveness of using AR-based learning in teaching computer science history using videos of historical figures. For the data collection, the authors analyzed students' scores in an achievement test and a five-point Likert scale questionnaire to determine students' attitudes and sense of accomplishment and to understand both classes' context. The experiment group had one more questionnaire for their perceptions of using the AR tool and additional questions about their experience.

A t-test confirmed the significance of the results, which confirms that AR indeed increased the interest and the sense of accomplishment as well as boosting comprehension among the experimental group students. On the other hand, in the usability questionnaire, question number 3, "Tablet (AR) was easy to use," 2% of the participants in the experimental group answered "Strongly disagree," and 12% answered "Neutral" to

question 4: "I had no problem using the tablet," 29% answered "Strongly Agree," 57% answered, "Agree." However, 14% answered "Neutral."

Given the lack of research experimenting with the use of Aurasma in high school education, this study adds a valuable contribution to showing that Aurasma can be useful to high school students. However, this study's pain point is not further investigating the usability issues hinted at by the questionnaire results. Because it is not covered in the study, the usability issues experienced by the participants remain unclear. The values in the results concerning the usability issues might not look alarming in the eyes of the authors, but they are still not to be ignored.

2.3.4 Trinity Students

Even post-secondary students seem to benefit from AR technology as a learning tool. Teachers often conducted lessons that utilize AR as a learning medium during field trips.

Some students also happen to be pursuing educational programs at the university, qualifying them as pre-service teachers, and having lessons with AR initiate them into thinking about utilizing AR tools as a learning medium in the future.

A case of three studies related to pre-service teachers (Delello et al., 2015) was discussed in a previous section. The two remaining cases looked into the perceptions of 63 human resources development undergraduate students and 40 marketing graduate students relating to using AR via the Aurasma application in their respective fields. After taking a pre-experiment survey, participants were given an assignment related to their significance using Aurasma and then taking a post-experiment survey. The post-experience survey

aimed to glean demographic information and an idea about the participants' technological backgrounds. The post-experience survey had five multiple-choice questions and three open-ended questions to determine the usability of students' perceptions after using the Aurasma application. The results indicated that most of the students, regardless of their discipline, had never used AR before and found Aurasma to be overwhelming in the beginning. Still, with practice, they noted that the creation of auras was exciting and fun and felt that it did enhance their courses. They also recognized Aurasma's potential as some human resources development students said they would use it professionally in the future for development and training purposes. However, participants conveyed some usability difficulties, ranging from problems uploading trigger images or large-sized videos to crashing for no reason. Participants also expressed the need for additional training and video support tutorials.

Like the other studies, this one showed the positive impact of AR on the students in enhancing their comprehension and their desire to use it professionally. However, there was a lack of objective measurement or experiment control group comparison, which might be a weakness.

Data analysis heavily relied on participants' subjectivity. Still, it emphasizes the same connectivity issues raised by the other studies and the need for more simplified instructions by video or text within the application itself, as well as challenges related to their own devices.

2.4 GAP ANALYSIS

Notwithstanding AR's educational abilities and learning enhancement capability, it remains far from being a mainstream e-learning technology. The shortage of AR educational research and the lack of educators' technical expertise alongside their low access to technology (Proctor et al., 2013) are some of the reasons why there is not enough research for AR authoring tools in AR-based teaching (Roberto et al. 2016). The lack of research is also a key factor contributing to AR's stagnation in educational usage; despite ongoing studies on AR for more than 40 years, only recently have researchers started investigating and evaluating AR authoring tools (Dünser et al., 2008). Along with the issues that occurred from insufficient technical knowledge needed to operate AR authoring tools (Kerawalla et al. 2006), there is a lack of applications specially made for education (Martin et al., 2011).

The teacher's role in introducing AR technology to the classroom is vital, yet many studies do not include them at all (Chang et al., 2014) or only include them briefly (Redondo et al., 2013). It is crucial for researchers to understand how educators will integrate AR into their classrooms, which will heavily influence the students' learning opportunities.

We identified a lack of thorough research on AR authoring tools for education as our central gap. Most of the educational AR studies discussed in the literature review emphasize students' feedback, behaviours, and emotions; they only allocate a brief section for teachers to describe how beneficial it is to learn with this technology. Moreover, since the teachers are most likely already familiar with the technology, it does not make those studies appropriate for exploring teachers' usability.

As much as it is vital to explore students' usability, it is also important to delve into the teacher's perspective using AR. For that purpose, we identified a need for a study analyzing raw, detailed input from teachers or pre-service teachers who have not been exposed to the technology before and who do not necessarily have a technological background in order to scrutinize their ease-of-use of this technology unbiasedly.

On the other hand, as students are expected to have no knowledge of AR, they need a tool that is easy to use, intuitive and requires little-to-minimum effort to learn, hence the need for a tool built around those users and involving them during its devolvment.

The lack of research on guidelines and models for developing educational AR authoring tools is the core gap identified in this research and the catalyst for developing CUAR. As the current AR authoring tools display considerable deficiencies, such as missing a system for the teachers to track student's activities on the application, we would try in this research to come up with some heuristics and guidelines needed to fill that lack and apply them while building the prototype.

In this thesis, we explore how to fill these gaps driven by the following questions:

- Does an AR authoring tool specifically designed for education create equal opportunities and feasibility for educators regardless of whether they have experienced AR in the past?
- Does an AR authoring tool designed for education will be more suitable in a classroom than using a general-usage AR authoring tool?

To answer those questions, we explored and reflected on the previous literature to develop some heuristics for educational AR tools, build a prototype based on those

guidelines, and evaluate it head-to-head with one of the best AR authoring tools in the current market: “Augment.”

CHAPTER 3: EDUCATIVE AR DESIGN GUIDELINES

In this chapter, some heuristics for developing educative AR authoring tools and the process of generating them will be presented. In academic writing, it is essential to narrow down the research scope; therefore, this thesis focuses on the technical difficulties found in AR tools while used in elementary school education and proposes guidelines for the design process of future AR development. Hence, those heuristics are not meant for designing a general AR application.

3.1 PROCESS

This section described the three steps we used to generate our heuristics for the educational AR authoring tool.

- *First phase: Related Work Scrutiny*

At the first stage, a summarization was conducted on all the technical difficulties in theoretical studies mentioned in Chapter 2 of this thesis and on other complementary research on mobile development heuristics/guidelines for school students in order to touch on real-world examples, such as students' and teachers' experiences and feedback on using authoring AR tools in the educational field.

- *Second phase: Trials*

To better understand the previously mentioned difficulties in the literature review, this phase was dedicated to testing existing tools in order to familiarize ourselves with the technology and to have field hands on the described issues.

The main goal was to generate ideas of interactions with those tools and to evaluate those ideas in future stages. At the same time, the goal was to simulate and note any personal thoughts about any potential issues that the research might not have covered in the related work section.

- *Third phase: Analysis*

Given the summary of Phase 1 and the notes from Phase 2, in this phase, an analysis was conducted to evaluate and classify all the inputs gathered in previous phases. Two methods were used during the analysis. The first was reverse thinking, which helps solve a problem by looking at it with a new paradigm. In this case, the process was to identify how everyone would think about the issue in a particular scenario then reflect on the outcome by thinking oppositely.

Another method was the filling the gaps process, which requires filling a gap between a pre-determined starting point and an endpoint, which is the goal. This method is a simple reflection on a problem using critical thinking to solve it. Once a solution comes to the mind, it must be written down and reflected on.

We also researched and extracted some general guidelines for developing mobile device applications for school children's educational use and cross-checked them with the challenges discovered in Chapter 2 in order to narrow down and cite only the guidelines

that might develop AR authoring tools for education. Those guidelines and references are mentioned in the next section accordingly.

3.2 GUIDELINES / HEURISTICS

This section is divided into categories; each category contains a definition of its meaning and context, the suggested heuristics, and examples of how interactions occur in each one are presented. Separating the categories into Devices, User Interface, Assets, Markers, Learning Management System, and Integrity allows a comprehensive model to cover all the parts, aspects, and software components of a mobile AR system to be created.

3.2.1 Devices and Infrastructure

This section is more about optimizing the AR in the classroom than the AR tool itself. In this context, the device refers to the AR mobile system device used by the teachers and students to augment their environment. The manipulation of this device is the liaison between the user and the augmented objects in space. On the other hand, the infrastructure encompasses the devices and any other technological means in the environment to augment the environment, e.g., internet connection.

Analysis:

- BYOD: The “bring your own device” approach was followed in almost every previously mentioned paper since it can significantly facilitate the experiment's conduct. It is a medium for teachers to overcome limitations such as the budget required to provide students with devices and device maintenance costs. However,

it does generate an uncontrolled side, specifically when a teacher in this context is unable to help subordinates with technical issues related to their own devices. Additionally, the brought devices might not be compatible or may not fulfill the minimum hardware or software requirements. With BYOD in education settings, it is expected that any technical challenges that occur in a lesson or a study are due to using multiple types of devices. Akçayır et al. (2016) stated that using various devices in AR applications can beget additional technical problems.

- Wi-Fi: It is an essential environmental infrastructure component. The nature of the application discussed in related studies relies 100% on the internet connection to download and view the augmented content. An unreliable WIFI connection during the experiment will throw away all the efforts made towards its success at other levels.
- Device proprieties: Besides the device's hardware and software minimum requirements to run the AR experience, it was found that the device's screen size and battery capacity were among the causes of some of the drawbacks and challenges in using MARS in classrooms (Chen et al., 2008).

Guidelines/Heuristics:

- Device (where possible): The teacher provides a pre-tested compatible device for each user to ensure a controlled and device issue-free experience. The device should have the minimum hardware and software required to run the AR experience and have an appropriate battery capacity to maintain power availability throughout the whole lesson.

The device's screen size should be large enough to display the augmented content and not large to the point of being uncomfortable to hold the device. The screen must be clear and versatile for multiple sizes (Revelle et al., 2009).

- Internet connection: The teacher ensures a reliable internet connection is available for the experience with adequate speed if the application/tool is required.

3.2.2 User Interface

The user interface refers to the elements in MARS like menus, buttons, icons and windows, which are often composited on MARS' screen and allow user interaction with virtual space. These elements can be placed on top of the device or overlaid on top of the augmented virtual object.

Analysis:

- Control: Users required a form of responsive interactions and control over the augmented objects to manipulate them, which allows a better understanding of the characteristics and relationship of the content, which can be too small sometimes.
- Support: In the previously discussed literature, users expressed the need to have within the application instructions and support to be able to perform the required tasks.
- Intuitive: AR may be very time-consuming for the user who may not have the technical skillset for the technology's complexity.

Guidelines/Heuristics:

- User Interface: The user interface needs a consistent design and straightforward menu without text. Have one clear layer menu with direct access (Hourcade et al.,

2008). It should not contain any phantom icons, and the displayed icons should be large, comfortable to select (Wolock et al., 2006), and visually meaningful (Hanna et al., 1998).

The menu must be accessible everywhere (Wolock et al., 2006) and be visually pleasing and adequate for the overall design (Korhonen et al., 2006). Furthermore, identical learning objects must be formed in an identical style (Alsumait et al., 2009).

The device must have the ability to switch between landscape and portrait positions while maintaining a prudent response to the tilt movement (Revelle et al., 2009).

Avoid positioning the buttons close to the edges of the layout or the screen (Chengdong et al., 1992).

Control keys must allow reposition, flip, scale up and down, and rotation of the augmented content. Furthermore, keys must be consistent and follow standard conventions while being logical and minimalist (Korhonen et al., 2006).

- Help page: The application must provide in-app links and buttons to show additional explanatory text and imagery/video support tutorials to help users perform the required actions. The instructions must be in clear speech, be context integrated (Wolock et al., 2006), age-appropriate, easy to grasp and recall, and not distractive (Korhonen et al., 2006).
- Ease of use: The application must be generally easy to use and technophobe friendly. It must only require age-appropriate skills (Wolock et al., 2006), have wide placement for selecting, dragging and tracking (Hourcade et al., 2008), and

show consistent, quick and clear responses to user actions without stagnation (Pinelle et al., 2008).

3.2.3 Assets

“Asset” refers to the objects overlaid and placed into the environment by displaying them on the MARS’ screen but does not include its user interface elements.

Analysis:

- Library limitation: The application library for digital content is considered very limited in terms of models and media that users can choose from to overlay on the physical space.
- Assets support high-quality visual graphics, effects, and audio (Bieke et al., 2007), (Korhonen et al., 2006). They are not distractive from educational intentions while being consistent with the learning process (Alsumait et al., 2009).
- Dependency on the marker: If the augmented content also has animation or video, it can be exhausting to stay still and hold the device facing the marker to view it.
- Multiple overlays: It is not possible to read multiple markers and overlay multiple augmented objects simultaneously.
- Collision detection between augmented content.
- Third-Party capabilities: Issues related to uploading videos and models as digital content from other sources like YouTube, Vimeo and applications might generate errors due to content size or compatibility.

Guidelines/Heuristics:

- Accessibility to a shared digital content library across other AR tools in the same genre allows collaboration options (Bieke et al., 2008). The library must offer an adequate amount of content that provides in-depth and applicable learning (Wolock et al., 2006).
- The ability to lock the augmented content on the screen without holding the device facing the target.
- Sound adjustment capability (Pinelle et al., 2008).

3.2.4 Markers

Generally, AR applications are either geo-based or vision-based. The first category uses the devices' global positioning system (GPS) plus the gyroscope and accelerometer to determine the device's physical location and its direction to superimpose the virtual computer-generated assets on the device's screen. This category's drawback is the inability to locate the position-target precisely, mostly indoors, due to the current GPS technology limitations.

The second category, vision-based AR applications, uses an image recognition protocol to identify a real-world image (marker-based) and overlays the virtual computer-generated assets on the device's screen on top of it. This category is more suitable in classrooms where teachers provide their students with textbooks containing images to be recognized by the device (AR application) and to fire the event that overlays the asset (Mota et al., 2006).

Markers refer to the object, which links the real-world environment and the augmented one. Markers (targets) are physical objects that can be detected through the

device camera. The relationship between the marker and the device includes the user's perception and interaction with the marker. This relationship can generate a variety of experiences since it depends on the physical space parameters like the distance or the viewing angle between the device and the marker.

The interactions between the user and the device in a relationship with the marker help discover the augmented environment by guiding the user through it and keeping him/her within marker limitations.

Analysis:

Analyzing marker issues revealed that they affect users' experience as much as any other category despite the often-mistaken perceptions allocated to them. For example, markers can cause application difficulties when they become harder to scan due to light reflections. They can also cause fatigue to the users or make them uncomfortable if they need to reposition themselves or stand up and hold the device for a long time to be able to view a long video or animation.

Another limitation observed is that only one marker can be detected at a time.

Guidelines/Heuristics:

- Markers must be non-reflective materials and easy to scan by the device's camera.
- Scanning must be optimized to read the markers from multiple angles.
- A marker does not need to be scanned in whole necessarily.
- After scanning a marker, users do not need to hold the device facing the camera/marker for the whole experience time.
- Multiple trackable markers support.

3.2.5 Learning Management System

LMS refers to the post-experience gains from the tool itself. This category helps to set up a way to extract information about the users, infrastructure, and markers after the AR experience. It is generally accepted that teachers play a significant role in classrooms, especially with elementary students. As young students usually do not take formal exams, the teacher's role is more fundamental, consisting of regularly evaluating their progress. While non-commercial subscriptions in AR authoring tools, e.g., Aurasma, do not provide statistical data (Scrivner et al., 2016), teachers must have a system that facilitates tracking students' activities and evaluating their progress.

Analysis:

- Metadata: A massive drawback in the current AR application is not allowing teachers to record any information or metadata related to students' use. The teachers would like to know objective metrics about the experience, including time consumption, augmentation lifetime, and error reports.
- Assessment: The lack of post-experience assessment to measure students' acquired competencies in the application to study students' development and experience can impact them.

Guidelines/Heuristics:

- Users' activity metadata must be recorded (where, when, who, how.) and reported to the server accessible by the teacher.
- Users' competence assessment post AR experience option as a questionnaire to assess the student's achievement and report it back to the teacher (Wolock et al., 2006).

- User self-assessment functions to help advance students' sense of achievement (Alsumait et al., 2009).
- User in-app feedback must be descriptive (Veletsianos et al., 2010), age-appropriate, context-related (childrennow.org), and involve meaningful sounds and graphics (Alsumait et al., 2009).

3.2.6 Integrity

Integrity is a category that summarizes the few non-categorized issues to ensure that the application runs without any sudden difficulties related to its early development phase.

Some issues revealed in the experiments discussed in Chapter 2 are:

- Technical issues while creating a channel in Aurasma, for example.
- Overlaying the wrong digital content on the marker.
- Tool crashing for no reason.

Those issues could not be categorized due to the lack of precise descriptions and information about them. However, it could be said that more rigorous tests during the development of the tool could help avoid any unexpected issues like crashing for no reason and could render it able to handle interruptions reasonably (Korhonen et al., 2006).

There is also a need to ensure availability in various devices (Alsumait et al., 2009) to prevent any data leaks and ensure personal information privacy.

3.3 SCOPE OF GUIDELINES

The guidelines suggested in this chapter are based on our knowledge acquired while reading and studying previous research and experiments involving AR in education and by reflecting on possible scenarios and other problems that may develop for the students/teachers while experimenting with AR in an elementary classroom. These heuristics are specific to mobile AR systems related to education. Hence, it is only this specific part that has been addressed. Many other fields, levels, and AR technology applications have requirements and technical limitations that require their own respective studies and guidelines.

CHAPTER 4: CUAR DESIGN AND DEVELOPMENT

In this chapter, we present the design and documentation related to the implemented solution, including information about the prototype of CUAR. The application CUAR developed for this study is an interactive AR authoring tool that provides elementary school teachers/students with a more suitable AR experience, reducing the compromises, difficulties, and technical issues found in other tools.

4.1 SYSTEM OVERVIEW

The overall system was based on a client-server architecture developed using the Unity 3D game engine for multiple platforms, including Android mobile applications and other tools, Vuforia AR SDK.

Unity 3D was used to develop the CUAR mobile application element to display AR resources and allow interactions. We developed a website platform to manage the AR content, as well as the participant database, progress and answers.

4.1.1 Functional Analysis

We describe CUAR as an AR educational authoring tool. Its overall function is to allow elementary school teachers to add virtual content like 3D objects, videos or images to their paper-based physical books and notes. Moreover, since the AR-type used is vision-based, students use the provided markers and CUAR mobile platforms to access the virtual content triggered by their textbook's marker. Within this overall functionality, we distinguish many CUAR functional and non-functional requirements as follows:

4.1.1.1 Functional Requirements

- **Web platform**

In the CUAR web platform, after a successful login, the system will allow the following input actions:

Add target: Gives the user the option to import and name a target, e.g., a picture marker, upload its related computer-content asset, and select its type, scale, and position.

Manage targets: Gives the option to edit the target's virtual content or delete it at once. It also gives the teacher the option to add multiple-choice questions (MCQ) into the target with four possible answers as an option for each MCQ question added.

Manage users (LMS): Gives the teacher the ability to review students' answers, monitor their activities (registration time, login time, projection of a target time) and delete students' accounts.

Manage teacher credentials: Gives the teacher the ability to edit their login and password or email address.

Manage Vuforia Keys: Gives the teacher the ability to update Vuforia Keys.

Access Video tutorials: This gives the teacher the ability to watch video tutorials of CUAR usability.

The system reactions and behaviour are basic and straightforward. The interface warns if any field is missing and asks for deletion confirmation.

- **Mobile Platform**

In the CUAR mobile platform, after a successful login, the user has the option to:

Scan target: Students can point their Android mobile cameras while CUAR is open to a target provided by the teacher by pressing the fingerprint shape button to scan the target and display its designated content.

Reposition target's displayed content: Students can manipulate the displayed content with the fingers to scale up, scale down or rotate it.

Answers targets' MCQ: Students can press the MCQ button to display the target's questions and answer them.

Release target: Students can press the release button to unlock the screen's display content to scan another target.

Screenshot capture: Students can press the camera icon to take a snapshot of what is displayed on the mobile phone and save it to the gallery.

Video capture: Students can press the recorder icon to take a video of what is displayed on the mobile phone and save it to the gallery.

Turn on flash: Students can turn on and off the mobile flash hardware by pressing the flash icon button.

Access help page: Students can press the help icon button to read instructions on using the application. They can also press the question button to open a webpage with video tutorials on CUAR.

4.1.1.2 Non-functional Requirements

CUAR non-functional requirements for both web and mobile platforms can be summarized as:

Intuitive: As the application is designed to enhance students' learning at a variety of educational levels, it should be intuitive and easy to operate without a demanding cognitive load.

Not demanding: To guarantee smooth usage across multiple Android devices and situations, CUAR should not demand a high level of internet speed to operate or require a high CPU load. It should also require only a small amount of the mobile device's storage space.

4.2 CUAR PROTOTYPE IMPLEMENTATION

4.2.1 Usability Goal and Testing

Our usability goal for the CUAR prototype is defined in two parts. The first is a 'teacher' who is the web-based platform administrator and prepares the virtual resource—which could be an image, 3D object or a video—and add it as an asset. This resource will be stored in the CUAR web platform library to be used by other teachers in future lessons for increased resource efficiency (Murray et al., 2003). If the teacher wishes to, they can assign questions to the asset for the students to answer.

The second part is where students log in to the CUAR Android mobile application, scan the marker (target), display the asset, and answer its related question.

4.2.2 DEVELOPMENT AND SOFTWARE DETAILS

The development of CUAR was based on the Waterfall Software Development Life Cycle Model (Ruparelia et al., 2010). This model seemed to be the most suitable for this thesis based on our requirements analysis performed in Chapter 3.

The fundamental stages followed in this model were: First, gathering the requirements analyzed in section 4.1.1. Second, identifying the design approach in section 4.2. Third, the implementation as described in this section. Fourth, it is going to be the evaluation of the prototype in Chapter 5. Since CUAR is still a prototype, there will be no maintenance phase in this cycle.

We acknowledge that adopting a Spiral Software Development Life Cycle would perhaps result in better prototyping. However, due to time constraints, SSDC would not be an option.

4.2.2.1 CUAR Web Platform

The CUAR web platform is an administration panel for the application. It is dedicated to being used mostly by the teachers in this study. They can exert all the previously mentioned functions to conduct the desired AR experience for the students.

The web platform's (Appendix A.1) back-end functionality relates to and links the information and the content uploaded by the teacher to the Vuforia AR SDK account. According to Wikipedia, *“Vuforia is an Augmented Reality software development kit for mobile devices that enables the creation of Augmented Reality applications. It uses computer vision technology to recognize and track planar images and 3D objects in real-time”*.

Vuforia's performance is acceptable in all aspects, images, text recognition, video playback, and processing. It is a paid, commercially used AR SDK, but what makes it suitable for this study is its reliability; it can maintain good battery life for hand-held devices (Grahm, 2017). We chose the Vuforia SDK to identify and track targets and project the images and 3D objects accordingly in real-time because it is suited to the Unity 3D rendering engine.

Vuforia will store the uploaded assets on its back-end database and allow the teachers full management of those assets from the front-end CUAR web platform. Vuforia provides one access key and one secret key that the teacher can easily integrate into the CUAR web platform.

Figure 2. Screenshot of the CUAR web platform.

4.2.2.2 CUAR Mobile Application

We decided to build CUAR's MARS on Android OS using Unity 3D, a cross-platform game engine for the mobile platform. Unity offers developers the ability to create

2D and 3D games by providing the necessary tools and features to quickly and efficiently build and program games. The version used for this prototype is “Unity 2019.4.10” (Appendix A.3).

Unity offers easy integration to Vuforia SDK for coding AR and functions. We used the Visual Studio integrated development environment and C# programming language to establish a back-end client-server link CUAR web platform (Appendix A.3).

- **Graphic Assets**

For the visual representation, we used Photoshop to create the interface’s visuals from rough initial sketches drawn on paper and assets like buttons and icons based on the guidelines discussed in Chapter 3.

Return home. (From help page)		Opens the help page. (From home page)
Open tutorials page. (Help page)		Scanning for a target. (Home page)
Submit the MCQ quiz. (Home page)		Record Video. (Home page)
OK button.		Open the MCQ quiz. (Home page)

Save screenshot. (Home page)		Releases AR content (Home page)
Scan for a target. (Home page)		Turn flash on/off. (Home page)

Table 1. Icon assets and functionality description

- Functions Design

While functions were coded using a C# programming language in Visual Studio, we used Photoshop to illustrate the initial interface design.

Figure 3. Functions design in Photoshop

CHAPTER 5: USER STUDY

5.1 EXPERIMENTAL DESIGN

We initially designed our user study in an elementary school environment to evaluate if teachers could easily use the CUAR prototype to build AR educational experiences without necessarily having a technical background. The goal was also to evaluate if the students could use CUAR to browse AR experiences without encountering any difficulties while gathering data about the prototype's design flaws flagged by participants.

However, as the experiment's timing coincided with the COVID-19 pandemic, making it difficult to recruit elementary teachers/students for a qualitative observational method in a classroom, we conducted a virtual usability study with a general user population referred to as “Trinity Students” as they are actual students in first and second higher education cycles.

The general user population group Trinity Students tested the overall usability of the CUAR AR browsing feature only, a task that we consider has a low complexity level and requires minimal cognitive and perception efforts; still, we acknowledge that it might result in some inaccuracies due to the age difference between our general users and elementary students. Nevertheless, it is not uncommon in HCI to conduct early or prototype usability studies outside the proposed group, e.g., Sakamaki et al., (2018). They conducted a prototype study on a general-user adult population meant to represent kids with impairment disabilities because the prototype did not have enough validity to be tested on their goal target group. Therefore, they made adult participants use their non-dominant hands and use glasses that alternated their viewing angle to mimic kids with

impairment disabilities. Our study suggests that the alternation of our main target goal with the general-user population group will not make an enormous difference in the prototype's ease-of-use results. It may provide even more profound and detailed insights about the prototype's areas of improvement.

On the other hand, we recruited pre-service teachers to conduct the virtual usability study with the CUAR AR authoring feature. In the context of this study, we consider pre-service teachers to be representative of our desired user population as they have already received some or most of their training as domain experts.

We designed two within-subjects experiments with two groups of participants: 10 participants in each experiment.

- In the first experiment, the 10 participants (general population users) would perform the exact same AR browsing tasks on the CUAR prototype mobile platform.
- In the second experiment, the other 10 participants (pre-service teachers) would create the same AR experience of their choosing twice, using the CUAR prototype and Augment successively, employing a counterbalancing measure to eliminate any order effects.

5.2 HYPOTHESIS AND METRICS

We primarily explored whether designing an educational AR tool following our deducted development heuristics would provide elementary school teachers and students with a more suitable educational AR tool.

We adopted a subjective measurements approach to measuring participants' perceived ease-of-use using three usability questionnaires, the Single Ease Questionnaire (Wetzlinger et al., 2014), a system usability scale (SUS) metric on a five-point Likert scale, where one is "Strongly disagree," and five is "Strongly Agree." We also partially used the USE (usefulness, satisfaction, and ease of use) Questionnaire (Lund Arnold M, 2001) to measure participants' preference between CUAR and the general-usage AR application "Augment" in terms of ease-of-use.

Additionally, we provided an opportunity for participants to provide feedback in the form of a series of open-ended questions.

We hypothesized that:

1. CUAR is equally usable for users with previous experience of AR as those without such experience (either browsing or authoring).
2. CUAR will achieve a higher usability score (according to the SUS) than the other compared general-usage AR authoring tool when used for an educational purpose.

We also expect this experiment to provide us with enough data about the CUAR prototype usability issues.

5.3 PARTICIPANTS

The experiment was conducted under Carleton University's permission and ethics board CUREB-B clearance #114533. The participants in this study were 20 adults between the age of 18 and 41, recruited through social media (Facebook groups); 10 participants

were Carleton University students from a variety of programs and education levels, including undergraduates, masters and Ph.D., hereby referred to as “Trinity Participants.”

The other 10 participants were students at the University of Ottawa Teacher Education program (holding a bachelor’s degree as a requirement to enter the program), hereby referred to as “Pre-Service Teacher Participants (PST).”

All participants signed a consent form and met the following criteria: 18 years of age and over, comfortable completing a questionnaire in English, familiar with surfing internet websites and smartphone applications.

5.4 PROCEDURE

5.4.1 Trinity Participants Study

As mentioned in section 5.1, the Trinity Participants were considered general population users and were used in place of elementary students to evaluate the browsing method's usability. They were asked to use two AR experiences that were pre-built by researchers.

We pre-prepared two AR experiences with two separate, commonly used assets in educational contexts: A video and a 3D model. The resources were randomly chosen in subjects related to science and art; these subjects were chosen for convenience as there are many educational resources. We should note that CUAR applies to any topic or environment; teachers are expected to apply their specific field with specific resources to teach any other subjects other than the ones highlighted in this study, e.g. (history, mathematics, electronics, and other subjects).

The AR contents were selected to be age-appropriate for our initial target group (elementary students). Since this study was focused on usability only, we did not administer any pre or post-test to evaluate learning.

For the first pre-built AR experience, its marker was an image that illustrates a virus (Figure 4). When the Trinity Participant scans target 1 with the CUAR mobile application, the image is replaced with an informative animation video about COVID-19 by “Free Medical Education” (Figure 5).

Figure 4. Target 1, Image Illustration of a Virus (Free Medical Education, 2020).

Figure 5. Video Asset Associated to Target 1 (Free Medical Education, 2020).

For the second pre-built AR experience, its marker was an artistic statue of a dragon from the internet (Figure 6). When the Trinity Participant scanned the dragon picture, a 3D model of a dragon was overlaid on top of it (Figure 7).

Figure 6. Target 2 a Picture of a Dragon Statue.

Figure 7. Screen Shot from CUAR with Dragon 3D Model Overlaid of Target 2.

We pre-built those AR experiences by creating a marker for each experience and uploading its asset (3D model and the animation video) via the CUAR web platform. We incorporated two questions for each experience, appeared to the Trinity Participants after pressing the quiz button (multiple-choice questions icon in the middle of the screen in Figure 7).

The Trinity Participants had four possible answers for each question. They selected either A, B, C, or D. When no questions were left, they were invited to press the submit buttons to send the answers to the web-platform server, to be stored for future marking by the “Teacher.”

The Trinity Participants were virtually recruited and invited to a one-on-one virtual meeting to conduct this usability experiment. We tried to focus on simple usability task testing to avoid overwhelming the participants so that they could provide more accurate

usage descriptions related to the rate of error, performance, ease-of-use, and user satisfaction.

Firstly, the Trinity Participants were tasked to fill in a demographic section to provide general information about themselves, such as age, gender, and the mobile device they used in the study and whether they had already experienced AR or not. They were then instructed to install the application on their Android devices such as a smartphone or a tablet, ensuring that the device had the minimum requirement of an 8-megapixel back camera, Android Marshmallow 6.0 and at least a late 2015 model for central and graphics processing unit requirements.

They were given a series of tasks to do with the CUAR mobile application depending on the target and the virtual asset linked to the marker. The series of the tasks were already predetermined by the researchers and can be summarized in:

<i>Action</i>	<i>CUAR Response</i>
Opening the application	CUAR opens, shows its logo while loading then prompts the user for full name and password.
Register/Sign in	CUAR asks for full name, email and password
Scan a marker	CUAR enters scanning mode and looks for one of its server database targets.
Resource display	The asset's display quickness depends on its size and the internet download speed available.
Consult help page	CUAR displays instructions on scanning a target and offers further help on the web help page.

Interact with projected content	Depending on the asset type, CUAR users can play, pause, rotate, scale-up/down, and release the projected asset. Trinity Participants can interact with the asset displayed through finger gestures. The interaction can be dragging and resizing the assets on the screen, moving, rotating, and if it is media content, it can be played and paused. The Unity3D engine gives CUAR a high capability of handling 3D object assets in terms of displaying the real-time interaction with ease and fluidity.
Record a video/Take a screenshot	CUAR enters screen capture or video capture mode and asks for saving confirmation
Answer MCQ Quiz	CUAR offers the ability to answer teachers' MCQs by clicking on the QUIZ button and on the submit MCQ button at the end.

Table 2. Summary of Tasks Performed by Trinity Participants Study

Trinity Participants were asked to rate every task using an adapted Single Ease Question (SEQ) (Appendix B.1) on a five-point, with one being 'Very difficult' and five being 'Very easy.'

The SEQs are requested promptly after each task to meter the trinity participant's attitude toward the recently attempted task experience.

This approach can give us ideas about the task completion rate and time needed by collecting the metrics separately by observation. According to Sauro Jeff et al., (2009), although the modesty of SEQ performs better than other complicated task difficulty measurements like Usability Magnitude Estimation or Subjective Mental Effort Questionnaire.

After completing all the tasks, Trinity Participants were invited to fill the SUS and the ease-of-use of the whole experience using the CUAR prototype mobile platform. SUS is a reliable, low-cost usability scale that can be used for global assessment of system usability. It provides measurements of usability and learnability comparable to industry benchmarks.

After completing the SUS survey, trinity participants were invited to provide additional feedback on the application via an open-ended questionnaire section. In this section of the survey, they were invited to indicate whether they encountered any technical or cognitive challenges and provide any additional feedback about what they liked about using CUAR and suggestions for its area of improvement.

5.4.2 Pre-Service Teachers Participants Study

Pre-Service teachers were considered as teachers' candidates, representing elementary school teachers. At the start of the study, participants were invited to a virtual meeting that functioned as an intake interview. The meeting began by explaining the experiment's procedure, followed by a demographic form completed by the participants. Then they were instructed to prepare an educational resource that can be taught in elementary school with AR and to develop an AR experience twice, first using the CUAR prototype's web platform and then using the Augment general-usage AR authoring tool.

Contrary to the Trinity usability study in which participants were given step-by-step instructions, pre-service teachers were provided with instructions only at the start of the study. This approach simulated a real-life scenario and helped us to assess how intuitive the content creation interface was for non-technical users or for users who are not domain experts in AR.

As a counterbalance measure, five pre-service teachers, hereby referred to as Group A in the next chapter, were instructed to start the experiment with the CUAR prototype first. The remaining five pre-service teacher participants, hereby referred to as Group B in the next chapter, were asked to begin with the Augment tool first. This measure was put in

place to avoid any order effect that would affect the participants' responses to the questions, either due to order or learning or fatigue, and to prevent biases in our data.

Whether the participants started with the CUAR or the Augment tool, they were instructed to complete the questionnaire related to the tool they experimented with successively after creating and testing their built AR experience with it.

The questionnaire was a SUS (Appendix B.2) survey to rate their usability experience on a five-point Likert scale.

When the pre-service teacher participants completed the building of their AR experience in both tools and filled their SUS surveys accordingly, we asked them to take a comparative survey (Appendix B.2) where they checked which tool, in their opinion, was more true to a given statement from the Ease-of-Use section of the USE questionnaire (Lund Arnold M, 2001).

Similar to the Trinity Participants survey, pre-service teacher participants had the same series of open-ended questions at the end.

CHAPTER 6: RESULTS AND DISCUSSION

6.1 RESULTS

6.1.1 Trinity Participants Results

In this section, we present the questionnaire results (Appendix B.1) broken down into sections. The questionnaire (Appendix B.1) was completed by the Trinity Participants group while performing the experiment described in section 5.4.1.

6.1.1.1 Single Ease Questionnaire Results

- Participants Rating

We calculated ratings (Appendix C.1) averages for each participant for all the tasks. We represented them in the following bar graph, mentioning whether the participants had any AR experience before this experiment or not by representing “YES or NO” above the identifier of each participant.

Figure 8. Bar Graph Representation of Participants' Rating Averages and Medians

We notice that all the participants who never had AR experience before this experiment have an average rating below 4.00. Furthermore, participants who had already experienced AR in some form (either browsing or authoring) have an average rating of 4.00 and above.

To verify our hypothesis 1.1 (Post AR experience has no significance on CUAR usage by students), we defined:

- H0 (null hypothesis): There is a difference between AR experienced and AR inexperienced participants' CUAR usability scores
- H1 (the alternate hypothesis): There is no difference between AR experienced and AR inexperienced participants' CUAR usability scores.

We ran a Wilcoxon Rank-Sum test by answering the question of whether there is enough evidence to suggest that the medians of participants with a post-AR experience are no different from the medians of participants without post-AR experience. We ranked the data from both samples, summed up the ranks of AR-experienced participants $T_Y=28$ and AR inexperienced participants $T_Y=16$ which makes our test statistic $T1=16$.

The $n1=4$, which is the number of observations in the smallest sample (non-experienced participants), and $n2=6$ is the number of observations in the largest sample (experienced participants).

According to Wilcoxon Tables of Distributions and Critical Values, our critical values for this hypothesis test are between 12 and 32 in a 2-tail test at alpha level $\alpha=0.05$. Our $T1=16$ is set within these critical values, which means we cannot reject the null hypothesis H0 in this case. This does not mean that H0 is true. It simply means that there is not enough

evidence to support that there is no difference between the score medians of AR-experienced and AR-inexperienced students.

Medians	RATING	RANK	Count	RANK SUM
AR Experienced	4	3.5	6	41
	5	8.5		
	5	8.5		
	5	8.5		
	5	8.5		
	4	3.5		
AR Inexperienced	4	3.5	4	14
	4	3.5		
	4	3.5		
	4	3.5		
z	4.05081		μ_w	22
p-value	0.99997		σ_w	4.6904158
Alpha < p; Fail to Reject H0			Alpha	0.05

Table 3. Excel Z Calculated Wilcoxon Rank Sum Test

- Task Rating Percentages

For each of the tasks given to the participants to perform and rate, we found the following:

Figure 9. Tasks' Ease of Use Rating by Participants

For task n°1: Install the application on your Android device, 40% of the participants found this task very easy to perform; 20% of the participants found this task easy to perform, and 20% have an undecided/neutral opinion about how easy it to perform. A total of 20% of the participants found this task challenging to perform. None of the participants found this task very difficult to perform.

For task n°2: Open the application and register, 50% of the participants found this task very easy to perform; 40% of the participants found this task easy to perform; 10% of the participants have an undecided/neutral opinion about how easy it is to perform. None of the participants found this task difficult or very difficult to perform.

For task n°3: Sign-in, 100% of the participants rated this task very easy to perform because the application signed them indirectly after signing up.

For task n°4: Scan Target 1, 30% of the participants found this task very easy to perform; 50% of the participants found this task easy to perform; 20% of the participants have an

undecided/neutral opinion about how easy it is to perform. None of the participants found this task difficult or very difficult to perform.

For task n°5: Open quiz MCQ and submit your answers, 20% of the participants found this task very easy to perform; 70% of the participants found this task easy to perform; 10% of the participants have an undecided/neutral opinion about how easy it is to perform. None of the participants found this task difficult or very difficult to perform.

For task n°6: Open quiz MCQ and submit your answers, 50% of the participants found this task very easy to perform; 40% of the participants found this task easy to perform; 10% of the participants have an undecided/neutral opinion about how easy it is to perform. None of the participants found this task difficult or very difficult to perform.

For task n°7: Scale-up and down, rotate the 3D model, 10% of the participants found this task very easy to perform; 50% of the participants found this task easy to perform; 40% of the participants have an undecided/neutral opinion about how easy it is to perform. None of the participants found this task difficult or very difficult to perform.

For task n°8: Open quiz MCQ and submit your answers, 60% of the participants found this task very easy to perform; 40% of the participants found this task easy to perform; None of the participants have an undecided/neutral opinion or found this task difficult or very difficult to perform.

For the last task, n°9: Take a snapshot and record a short video and save it in your phone's gallery, 40% of the participants found this task very easy to perform; 30% of the participants found this task easy to perform; 20% of the participants have an undecided/neutral opinion about how easy it is to perform; 10% of the participants found

this task difficult to perform. None of the participants found this task very difficult to perform.

These results do not contribute to the research's hypothesis. Still, it does contribute to the overall study by providing an analysis ground to analyze the CUAR's functionalities that tend to be more difficult for the participants and work on fixing them for the final version of the prototype.

6.1.1.2 System Usability Scale

We calculated the System Usability Scale score for each user and represented it in this bar graph:

Figure 10. Trinity Participants System Usability Scale Scores

Participants with past AR experience have a usability score average of 68.75, which is above average. On the other hand, participants with no past AR experience scored an average of 61.25, which is under average.

The total average for all participants is 73.75, which falls above the 67th percentile rank (B-) (Appendix D), which makes it a “Good” rating score for CUAR.

This section presents the year model of each participants’ device and RAM capacity. We noticed that it might be a correlation between the devices’ data presented and some of the students' challenges.

Figure 11. Trinity Participants' Devices by Years and RAM Capacity

6.1.2 Pre-service Teacher Participants Results

In the following, we state the results of the ten pre-service teachers’ participation in the questionnaire (Appendix B.2) and highlight the results of each section of the questionnaire.

6.1.2.1 Group A

Group A is pre-service teacher participants who ran the experiment on CUAR first, then Augment. We will present their CUAR usability scale score first, then their Augment usability score. And then, we present the participants' comparison form results.

- CUAR System Usability Scale

Figure 12. Group A System Usability Scale Scores for CUAR

Group A participants with past AR experience have a usability score average of 85.83. Participants with no past AR experience scored an average of 75.

The total average for Group A participants for CUAR is 81.5.

- Augment System Usability Scale

Figure 13. Group A System Usability Scale Scores for Augment

Participants with past AR experience have a usability score average of 60.

Participants with no past AR experience scored an average of 52.5.

The total average for Group A participants for Augment is 57.

We also present in this section group A participant's devices' year of release and RAM capacity.

Figure 14. PST Group A Participants' Devices by Years and RAM Capacity

6.1.2.2 Group B

- Augment System Usability Scale

Figure 15. Group B System Usability Scale Scores for Augment

Group B participants with past AR experience have a usability score average of 73.75. Participants with no past AR experience scored an average of 55.0.

The total average for Group B participants for Augment is 62.5.

- CUAR System Usability Scale

Figure 16. Group B System Usability Scale Scores for CUAR

Group B participants with past AR experience have a usability score average of 82.5. Participants with no past AR experience scored an average of 63.3.

The total average for Group B participants for CUAR is 71.5.

We also present in this section Group B participant's devices' year of release and RAM

Figure 17. PST Group B Participants' Devices by Years and RAM Capacity

capacity.

6.1.2.3 Group A and B Comparison

- SUS Scores Comparison

We calculated the average usability scores for all pre-service teachers for both CUAR and Augment: the CUAR SUS score average is 76.25, and the Augment SUS score

average is: 59.75. We notice a difference between the two applications' usability, and we ran a two-tails Paired T-Test to make sure this is not due to chance.

Figure 18. PST SUS Scores for CUAR and Augment

According to De Winter et al., (2010), a T-Test is valid in this verification. It provides almost the same results as the Mann-Whitney by providing the same protections against false negatives and false positives for sample sizes of 10 on the Likert scale data. To verify hypothesis 2 (CUAR would have a better usability rating than Augment in an educational setting), we defined:

- H0 (null hypothesis): There is no statistically significant difference between CUAR's and Augment's usability score.
- H1 (Alternative hypothesis): There is a statistically significant difference between CUAR's and Augment's usability scores.

We used the average calculated from data given in figure 18 and the t-value obtained from the calculation in Table 3, 3.03, which is higher than the critical value 2.1, which allowed

us to reject the null hypothesis; therefore, there is a statistically significant difference between usability score of CUAR and Augment, $t=3.03$, $p<0.05$.

	CUAR SUS SCORE	Augment SUS SCORE
Mean	76.25	59.75
STDVE	12.81546375	11.45340803
Variance	164.2361111	131.1805556
Count	10	10
T-Value	3.035753102	
Alpha Level	0.05	
Degree of Freedom	18	
Critical value	2.1	

Table 4. CUAR and Augment SUS Scores Averages T-Test Data

We would also like to point out that we notice a decreasing trend in terms of usability score for participants who started the experiment with CUAR followed by Augment in figure 19, contrary to an increasing trend for most of the participants who started the experiment with Augment then did CUAR, except for one participant who had a slight decrease.

Figure 19. Pre-Service Teachers Usability Scores Trends

- Ease of Use and Learnability Comparison

In this section, we present the results of a comparison table in part 3 of Appendix B.2. Multiple ease-of-use and learnability statements were given to participants who needed to choose the tool (CUAR or Augment or neither) that corresponded the most to the given statement based on their subjective opinion after using both tools.

Figure 20. PST Votes to Questions Related to Ease of Use and Learnability

- CUAR Usability between AR experienced and inexperienced PSTs

We ran another comparison similar to the one done in section 5.4.1.1 to compare between the CUAR usability score of pre-service teachers' participants who have experienced AR in some form in the past and pre-service teachers who have never experienced it.

Figure 21. Pre-Service Teachers CUAR SUS Score

For statistic verification, due to the participants' small sample size and due to the fact that the SUS is based on non-parametric data, we will use the Mann-Whitney test, equivalent to a t-test for parametric data and sample from 10 and above.

The Mann-Whitney U test's *U-value* reflects the difference between the sum of the ranks of each pair. We ranked all participants from 1 to 10 and gave the tied scores the average of their respective ranks. Then we calculated the U statistic for each pair based on the sum of its ranks. The lowest one is the *U-Statistic* for the test, and we compared it to

the critical value of The Mann-Whitney U table based on the number of observations and the *U-Statistic*.

To verify hypothesis 1.2 (Post AR experience has no significance on CUAR usage by pre-service teachers), we defined:

- H0 (null hypothesis): There is a difference between AR experienced and AR inexperienced PST CUAR usability scores.

H1 (the alternate hypothesis): There is no difference between AR experienced and AR inexperienced PST CUAR usability scores.

To check the verification of these hypotheses, with the Mann-Whitney U test, we calculated the following sums: the experienced PSTs ranks $\Sigma_{exp} = 37$ and its respective $U_{exp} = 22$, the inexperienced PSTs ranks $\Sigma_{inexp} = 18$ and its respective $U_{inexp} = 3$ which becomes the *U-Statistic* = 3 as the smaller the *U* value, is less likely to occur by chance. Based on the critical values *U* table and our number of observations $n_1 = n_2 = 5$, we obtain *U-critical* = 2 at $p < 0.05$. We found that *U-Statistic* is not smaller than *U-critical*. Therefore, we cannot reject H0, meaning that we do not have enough evidence to support that post-AR experience does not affect pre-service teachers' ease of use for CUAR.

PST CUAR Scores	RATING	RANK
Experienced	87.5	8
Experienced	75	6
Experienced	95	10
Experienced	72.5	4
Experienced	92.5	9
Inexperienced	77.5	7
Inexperienced	72.5	4
Inexperienced	72.5	4
Inexperienced	65	2
Inexperienced	52.5	1

	RANK SUM
Experienced	37
Inexperienced	18
Exp Observations (n1)	5
Inexp Observations (n2)	5
μ_w	27.5
σ_w	4.787135539
z	1.984485278
p-value	0.976399116
alpha	0.05
Reject?	Fail to Reject Null

Table 5. Mann-Whitney U Test Using Z Value and Normal Distribution Table

6.2 Discussion

Findings from the usability testing experiment suggested that the developed AR prototype for education usage, CUAR, could be a more user-friendly alternative for such a technology in classrooms. It facilitates teachers' authorship with or without a technical background to build real AR experiences and take advantage of CUAR multiple-choice question and learning management functions. CUAR could also be an easy-to-use alternative AR browsing tool for elementary school students.

Participants were able to interact with the prototype independently and only asked questions about the experiment procedure initially. However, the concluded experiments identified that some participants might have difficulties operating CUAR on their phones due to the demanding power of the CUAR mobile system. This usability issue could make it difficult for some students to use CUAR if they bring their devices and they do not meet the minimum hardware requirements.

We break down the analysis and discussion of the results into two sections. First, we looked at the usability testing resulting in an objective measurement based on the participant's subjective rating. Then we looked at the subjective feedback gathered from the subjective, open-ended comments sections (Appendix B.1 and B.2).

6.2.1 Subjective Measurements Discussion

- Trinity Students

In the single-use questionnaire, the average rating of all the Trinity Participants in all tasks was 4.23, which lies between “Easy (4)” and “Very Easy (5)”. These results gave

us confidence that a teacher would instruct their students within the CUAR mobile system would not encounter any difficult challenges.

The same participants took a system usability scale questionnaire for the same CUAR mobile system, and the average for all Trinity Participants reflected the ease of single ease results. According to Sauro Jeff, 2018 (Appendix D), a SUS of 73.75 has a percentile between 65% and 69% and falls between “Good” and “Excellent” in terms of adjectives. As our MARS is still a prototype, we find these results very promising and encouraging in terms of the simplicity of its tasks, and it still gives us room to work on its perfection.

However, we could not determine if Trinity Participants who had never used an AR system before would find CUAR as easy as those already familiar with such a technology. We think there might be many reasons: one, the small sample we were able to recruit for the experiment; another reason might be that the age bracket of the participants might affect their rating in any way, or perhaps the CUAR mobile app is simply not as intuitive for AR experienced users as it is for the inexperienced user.

- PST Group A

As for the pre-service teachers’ results (group A), the average of their system usability scale result is 81.5 for CUAR and 57 for Augment. In this experiment, participants tested both apps’ web administrative platforms and mobile AR systems. The rating of CUAR is labelled as “Excellent” and falls into the 90% to 95% percentile range and grade “A,” according to Sauro Jeff., (2018). On the other hand, the same participants rated Augment a grade “D” with “OK” usability. Certainly, this rating does not detract from any

of Augment's success in the AR market. However, it shows that the specific task of creating teaching material with AR might not be as good as it is with CUAR.

- PST Group B

For the other pre-service teachers, Group B, the CUAR system usability score average was 71.5, and the Augment system usability score average was 62.5. CUAR ranked “C+” and “Good” on usability, and Augment still ranked “OK” with a grade of D.

We think that difference between the four rating averages of each group/system (Figure 19) comes down to the system the users tried first. Our rationale is that Group A tried CUAR and rated it as grade “A” after trying Augment and feeling more difficulty in performing the same task. They reflected that on their rating to express the challenges found in Augment and not in CUAR.

However, CUAR still rates better than Augment in the specific task given to the PST participants. In conclusion, we can verify our hypothesis 2, which states that CUAR will have a better usability rating than Augment.

Like Trinity Participants, for both groups A and B, we could not prove that CUAR is as intuitive for AR experienced pre-service teachers as it is for inexperienced pre-service teachers.

- CUAR Related Measurements

Based on the results of Tasks’ Rating Percentages in section 5.4.1.1, we obtained ease-of-use related data on each function of the CUAR browsing tool, which gives us an

idea of the tasks that presented more difficulties to Trinity Participants. We clearly notice the ease of use of Task N°5 and participants' hesitation on task N°7, for example (Figure 9). We discuss these difficulties in greater depth in the next section.

In section 5.4.2.3 (Figure 20), we used 15 statements from the USE Questionnaire (Lund, 2001) from the section “ease of use and ease of learning” as a reference for all PST participants to choose the system that represents the most the given statements. Two examples of those statements:

1. “System is easy to use”: 100% (All 10 PST participants agreed that CUAR is easier to use than Augment).
2. Which system “has technical issues?”: 50% votes neither, 30% CUAR and 20% Augment.

This metric gave us a clearer idea about the system that PST participants found to be easier and revealed that CUAR still has some pain points regarding technical difficulties.

6.2.2 Subjective Open-ended Comment Discussion

This section discusses the participants' responses (Appendix C.2) to the open-ended questions.

As much as we liked reading the positive reviews from participants, we focused on gathering any mentioned challenges, technical difficulties, and suggestions to improve CUAR. We performed an analysis on all the feedback, discarding any problem or suggestion not related to CUAR and its correct usage, and classified them using pie charts:

Figure 22. Encountered Challenges per Participants Percentages

Figure 23. Suggested Improvements per Participants Percentages

We classified the discarded comments and the reason behind discarding them (Appendix C.3). The other challenges and suggestions gave us a very good idea of CUAR's compromises and usability issues that should be fixed. In particular, one challenge mentioned by 40% of the participants and suggested as an area of improvement by 45% of the participants is "performance optimization." This classification included every participant feedback mentioning that CUAR freezes or does not run as smoothly as it should or shuts down.

We looked into the participants who mentioned this issue, and we thought there is a correlation between their devices and their comments. We believe the reason behind the challenging performance of CUAR is their devices, which are either a few years old or have a slower RAM capacity (Figures 11,14,17).

We classified the devices in the following table:

Participants	Phone	Year	RAM
S04-CUARO	Samsung A51	2020	4
S06-CUARO	Huawei Mate 10	2017	4
S07-CUARO	Huawei P30	2019	6
S08-CUARO	Samsung A8	2018	4
PT02-CF	Xiaomi Mi Note 3	2017	6
PT04-CF	Huawei P10	2017	4
PT05-CF	Samsung Note 8	2017	6
PT01-XF	Samsung S7 edge	2016	4
PT04-XF	Oppo R11	2017	6
PT05-XF	LG G7 ThinQ	2018	4

Table 6. Table of Participants' Devices who Encounter Performance Issues in CUAR

We concluded that CUAR needs to be more optimized in its engine to run smoother in phones with a low RAM capacity or older generation processing chipsets.

6.2.3 Overall Findings

Participants' experience using the CUAR prototype in this evaluation was favourable. There have been many learning opportunities along the way for us by guiding participants on how to use the CUAR framework and to watch them interact with it virtually. Trinity Participants succeeded in going through the tasks when given consecutive instructions. The segmentation of tasks one task at a time was a key factor that we thought helped the Trinity Participants with the experiment. They did not feel overwhelmed by the enormity of the whole experience when going through it. This encouraged the participants to remain focused and to avoid frustration when faced with technical challenges. One task at a time, they rated each one as they progressed. They completed the experiment and tied it all together at the end to come up with comments and suggestions to the open-ended questions that will help us improve the CUAR prototype.

Pre-service teacher participants certainly took more time to perform their tasks as they were broadly instructed to create an AR educative experience on CUAR and Augment without much detail. Still, it did not prevent them from achieving decent usability results and providing us with important open-ended comments. We did not receive any improvement feedback about the CUAR web platform, so we assumed that pre-service teachers' participants had no issues with it.

Overall, we thought the experience was a unique learning environment for the participants and for us as researchers. We learned a lot of information that will help us to improve CUAR. We found that basing our prototype development on the heuristics informed by the literature review delivered a more suitable authoring tool for teachers.

We based this finding on the ease-of-use and usability score we extracted from the participants in general and the results of the comparison between CUAR and Augment in particular.

We clearly can deduce that CUAR outperforms Augment in terms of ease-of-use in an AR educational context. However, as Augment is a fully developed tool and CUAR still a prototype, Augment has the advantage in terms of optimization, embedded features, and the application's integrity as a whole.

Trinity Participants with both previous AR experience and inexperience found that the tasks are relatively easy to perform, except for task number 7, which asked the participants to rotate and flip the 3D model while the flip ability is not implemented in CUAR.

We also recognize that the experiment resulted in a very decent and encouraging SUS score for all participants, with the only differences being those between AR

experience and inexperience. Unfortunately, we cannot state that both categories would experience the same usability and same ease-of-use in CUAR. Still, we have enough data to work on that for future improvements.

We want to point out that many participants expressed their concerns about CUAR optimization issues. While we notice that most of those participants had a relatively lower grade device either in terms of RAM capacity or processor chipset (identified by device year of release), this optimization issue will be tackled as a priority in future updates of CUAR.

In general, because of the open-ended section in participant surveys, we believe that we gathered enough information about pre-service and Trinity Participants' usability to revise CUAR's functionalities and design to develop the official version: 1.0.

CHAPTER 7: CONCLUSION

7.1 SUMMERY of FINDINGS

This thesis aimed to verify the effectiveness of deduced guidelines from the literature survey of heuristics in creating a more suitable educational AR authoring tool for elementary school teachers to use in classrooms.

In the related work, we noticed a lack of research that focuses on the challenges encountered by either the students or teachers using AR technology for educational purposes. We also identified that the most used systems in this area are multi-purpose tools adapted to classroom usability but not dedicated to it. We have categorized the literature review and mentioned the problems encountered by students and teachers of various educational levels while using the described tools in their classrooms. We decided to focus on the usability issues more and discuss them more in greater depth.

Our main goal was to design and develop an educational AR authoring and browsing tool to support teachers and students in an elementary school who want to use this technology. We were able to create a research-based tool for the teachers to incorporate AR technology in their classrooms successfully. We hypothesized that the developed tool offers more intuitive usability than the other multi-purpose tools used in education, based on subjective evaluation criteria: the “ease-of-use.” This study's results supported our views and research on the importance of incorporating AR tool guidelines in developing educational augmented reality tools.

In principle, our study revealed our proposed guidelines informed by the literature review, resulted in some promising baseline towards developing an educational augmented

reality authoring tool. CUAR, the developed tool in this study, was found to be user-friendly because of its development guidelines informed by our related work-deduced heuristics.

7.2 LIMITATIONS AND FUTURE WORK

The research presented in this thesis has a subjective finding that cannot be applied to a broader audience in the educational system in general. The results have a low range of external validity due to the small sample size of participants involved in the usability study and their ages (18-41), which cannot be generalized to a broader demographic of students and teachers at all levels. Moreover, this “laboratory” type of empirical experiment also limited us by missing the classroom environment's complexity data.

Our initial plan for this study was to recruit a larger sample size of actual elementary school teachers and their students to conduct user-centred research (Abrás et al., 2004), which is a design methodology where the prototype is co-designed with the targeted users: elementary school students and teachers in this case. However, that plan was affected by an ongoing pandemic, COVID-19. As a result of the virus's spread, the government applied many restrictions that forced us to experiment virtually at a distance and drastically lowered participants' turnout for our experiment.

The compared software “Augment” is arguably one of the most used AR authoring tools on the market. Still, the comparison results with the developed prototype cannot be generalized to other AR authoring tools.

Another limitation lies in the usability testing methods conducted in this study, which could have used more in-depth testing and could have been more specific. For

example, we could have used the Chin et al., (1988) Questionnaire for User Interface Satisfaction (QUIS) to retrieve more data specific to the interface of the developed tool.

The findings offer a case-specific situational representation relevant to the context and participant demographic involved in this work.

Our direction for future work is to contribute to the work of this thesis towards a Ph.D. program, where the developed tool would be among a set of solutions to a more profound dissertation. While doing so, we foresee the following work implemented to this current contribution:

- Perfecting the developed prototype considering this thesis's results to include optimization, an assets library, and a 3D model suitable interaction. Developing a new SDK also allows us to manage CUAR assets internally and detach CUAR from the Vuforia database.
- The implementation of more features required in the educational field, e.g., multi-target tracking, a client-server architecture for assets library shareability, improving feedback capability, and improving the learning management system.
- Run more profound usability experiments involving a more extensive and diverse audience from elementary to trinity students and their respective teachers.
- Upon completing the prototype's final version, run a proper engineering research method to evaluate the proposed solution using quantitative and qualitative metrics.

APPENDICES

Appendix A : Screenshot of CUAR prototype Development

A.1 CUAR Web Platform

```
add-target.php
1 <?php include 'header.php'; ?>
2 <div class="container-fluid">
3 <form action="<?php echo htmlspecialchars($_SERVER['PHP_SELF']);>" method="post">
4 <div class="col-xl-12">
5 <div class="card border-left-danger shadow h-100 py-2">
6 <div class="card-body">
7 <div class="row no-gutters align-items-center">
8 <div class="col m-2">
9 <div class="text-lg font-weight-bold text-danger text-uppercase mb-1">Target Image</div>
10 </div>
11 <div class="col-auto">
12 <div class="fas fa-image fa-2x text-gray-300"></div>
13 </div>
14 </div>
15 </div>
16 </div>
17 </div>
18 <div class="card o-hidden border-0 shadow-lg my-5">
19 <div class="card-body p-0">
20 <!-- Nested Row within Card Body -->
21 <div class="row">
22 <div class="col-lg-12">
23 <div class="p-5">
24 <div class="form-group">
25 <label for="Target">Target</label><input class="form-control" name="targetname" placeholder="Enter target name" type="text" value="<?php echo $targetname">">
26 </div>
27 <div class="form">
28 <center>
29 <input type="file" name="file1" id="file1" onchange="loadFile(event)" class="inputfile" accept=".jpg, .jpeg">
30 <div id="imageText" style="padding-top: 56px; font-size: 20px; text-align: center; margin-top: 10px; height: 40px; width: 70%;"></div>
31 </center>
32 <div id="progressBar" value="0" max="100" style="margin-top: 10px; height: 40px; width: 70%;"></div>
33 <div id="loaded_n_total"></div>
34 <div id="help-block" id="status"></div>
35 </div>
36 </div>
37 </div>
38 <div class="text-center">
39 <button type="button" class="btn btn-danger" onclick="uploadFile()">Upload Image</button>
40 </div>
41 </div>
42 </div>
43 </div>
```

Figure 24. Web Platform Add Target Page Program in PHP Using Atom

A.2 CUAR Mobile APP

Figure 25. CUAR Mobile App Main Page Using Unity 3D

A.3 CUAR Mobile APP Programming

```

1  using System.Collections;
2  using System.IO;
3  using UnityEngine;
4  using UnityEngine.UI;
5
6  public class login : MonoBehaviour {
7
8      public InputField nickname;
9      public InputField password;
10     private string str;
11
12     public void callLogin()
13     {
14         StartCoroutine(userLogin());
15     }
16
17     IEnumerator userLogin()
18     {
19         MMForm form = new MMForm();
20         form.AddField("nickname", nickname.text);
21         form.AddField("password", password.text);
22         MMForm www = new MMForm(Savelink.Link + "userlogin.php", form);
23         yield return www;
24         if (www.text == "0")
25         {
26             Debug.Log("user logged in successfully");
27             str = nickname.text + "password.text";
28             remember();
29             StartCoroutine(addactivity());
30             UnityEngine.SceneManagement.SceneManager.LoadScene("main");
31         }
32         else
33         {
34             Debug.Log("user login failed.");
35         }
36     }
37
38     public void remember()
39     {
40         using (TextWriter writer = File.CreateText(Application.persistentDataPath + "/userSetting.txt"))
41         {
42             writer.WriteLine(str);
43         }
44     }
45
46     IEnumerator addactivity()
47     {
48         MMForm form = new MMForm();
49         form.AddField("user", nickname.text);
50         form.AddField("activity", "logged in");
51         MMForm www = new MMForm(Savelink.Link + "useractivities.php", form);
52         yield return www;
53         Debug.Log(www.text);
54     }
55 }

```

Figure 26. CUAR Mobile Login Page Program Using Microsoft Visual Basic

Appendix B : Experiment Questionnaires

B.1 Trinity Students' Experiment Questionnaire

Code:

Using the CUAR Mobile application found in <https://bit.ly/3kOw8V3>, Please perform the tasks below one by one; after each task is performed, please rate the task difficulty.

After all the tasks are performed, please proceed with the overall usability questionnaire.

I. Demographic Questionnaire

Age:

Gender:

Level of Education:

AR post-experience Y/N:

Device's make and model :

II. Task / Single Ease Question

Task N.1: Install the application on your Android device.	Very Difficult	Difficult	Undecided	Easy	Very Easy
After performing this task, please circle The rating.	1	2	3	4	5

Task N.2: Open the application and register.	Very Difficult	Difficult	Undecided	Easy	Very Easy
After performing this task, please circle The rating.	1	2	3	4	5

Task N.3: Sign-in	Very Difficult	Difficult	Undecided	Easy	Very Easy
After performing this task, please circle The rating.	1	2	3	4	5

Task N.4: Scan Target 1: https://bit.ly/307etQA	Very Difficult	Difficult	Undecided	Easy	Very Easy
After performing this task, please circle The rating.	1	2	3	4	5

Task N.5: Open quiz MCQ and Submit your answers.	Very Difficult	Difficult	Undecided	Easy	Very Easy
After performing this task, please circle The rating.	1	2	3	4	5

Task N.6: Release video projection and Scan Target 2: https://bit.ly/3n4V50C	Very Difficult	Difficult	Undecided	Easy	Very Easy
After performing this task, please circle The rating.	1	2	3	4	5

Task N.7: Scale-up and Down, Rotate and Flip the 3D Model.	Very Difficult	Difficult	Undecided	Easy	Very Easy
After performing this task, please circle The rating.	1	2	3	4	5

Task N.8: Open quiz MCQ and Submit your answers.	Very Difficult	Difficult	Undecided	Easy	Very Easy
After performing this task, please circle The rating.	1	2	3	4	5

Task N.9: Take a snapshot and record a short video and save it in your phone's gallery.	Very Difficult	Difficult	Undecided	Easy	Very Easy
After performing this task, please circle The rating.	1	2	3	4	5

III. CUAR Questionnaire

SUS:

	EASE OF USE 5 POINTS LIKERT SCALE	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
	CUAR:	1	2	3	4	5
1	I think that I would like to use this system frequently.					
2	I found the system unnecessarily complex.					
3	I thought the system was easy to use.					
4	I think that I would need a technical person (or instructions) to use this system.					

5	I found that the various functions in this system were well integrated.					
6	I thought there was too much inconsistency in this system.					
7	I would imagine that most people would learn to use this system very quickly.					
8	I found the system very cumbersome to use.					
9	I felt very confident using the system.					
10	I needed to learn a lot of things before I could get going with this system.					

Please describe any technical or cognitive challenges/problems encountered?

..

Open-end Comments:

- Your Review of the application:

..

- Suggestions for Improvements:

..

B.2 Pre-Service Teachers' Experiment Questionnaire

Code:

I. Demographic information

Age:

Gender:

Level of Education:

AR post-Experience Y/N:

The device used in this experiment:

II. CUAR Questionnaire

SUS:

	EASE OF USE 5 POINTS LIKERT SCALE	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
	CUAR:	1	2	3	4	5
1	I think that I would like to use this system frequently.					
2	I found the system unnecessarily complex.					
3	I thought the system was easy to use.					
4	I think that I would need a technical person (or instructions) to use this system.					
5	I found that the various functions in this system were well integrated.					
6	I thought there was too much inconsistency in this system.					
7	I would imagine that most people would learn to use this system very quickly.					
8	I found the system very cumbersome to use.					
9	I felt very confident using the system.					
10	I needed to learn a lot of things before I could get going with this system.					

III. Augment Questionnaire

SUS:

	EASE OF USE 5 POINTS LIKERT SCALE	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
	Augment:	1	2	3	4	5
1	I think that I would like to use this system frequently.					
2	I found the system unnecessarily complex.					
3	I thought the system was easy to use.					
4	I think that I would need a technical person (or instructions) to use this system.					
5	I found that the various functions in this system were well integrated.					
6	I thought there was too much inconsistency in this system.					
7	I would imagine that most people would learn to use this system very quickly.					
8	I found the system very cumbersome to use.					
9	I felt very confident using the system.					
10	I needed to learn a lot of things before I could get going with this system.					

IV. Both Apps Questionnaire

<i>Augment</i>	<i>Statement:</i> Which one is more	<i>CUAR</i>
	Easy to use?	
	Simpler to use?	
	User friendly?	

	Requires the fewest steps possible to accomplish what I want to do with it?	
	Flexible to use?	
	Effortless to use?	
	Can it be used without written instructions?	
	Usable without noticing any inconsistencies?	
	Quicker to learn?	
	To remember how to use it?	
	Easy to learn to use it?	
	Difficult to use?	
	Problematic to use?	
	Ambiguous to use?	
	To have technical issues?	

V. Open-ended Questions

Please describe any technical or cognitive challenges/problems encountered:

...

Please give a review of CUAR application:

...

Please suggest Improvements for CUAR:

...

Appendix C : Experiments' Results

C.1 Trinity Students' SEQ Experiment Results

CUAR SEQ	Participant	Task N° 1	Task N° 2	Task N° 3	Task N° 4	Task N° 5	Task N° 6	Task N° 7	Task N° 8	Task N° 9	Average	Median
	S01-CUARO	4	4	5	4	4	3	4	5	3	4	4
	S02-CUARO	5	5	5	5	5	4	5	5	5	4.888888889	5
	S03-CUARO	5	5	5	5	5	5	4	4	5	4.777777778	5
	S04-CUARO	5	5	5	4	4	5	4	5	4	4.555555556	5
	S05-CUARO	3	3	5	4	4	5	3	5	4	4	4
	S06-CUARO	3	4	5	3	4	4	3	4	5	3.888888889	4
	S07-CUARO	5	5	5	5	4	5	4	4	5	4.666666667	5
	S08-CUARO	2	4	5	3	4	4	3	4	2	3.444444444	4
	S09-CUARO	4	5	5	4	4	5	4	5	3	4.333333333	4
	S10-CUARO	2	4	5	4	3	4	3	5	4	3.777777778	4
	Average										4.233333333	4.4

Table 7. Trinity Students SEQ Detailed Results

C.2 All Participants Open-Ended Comments Results Analysis

➤ Trinity Participants comments:

- Challenges encountered

S01-CUARO: *For some reason, my phone won't pick up the marker initially, but I tried to lower the brightness of my screen and it just worked.*

S02-CUARO: *Overall performance is good, but I missed a few seconds of the video and couldn't replay the desired section. The video rewind option would have been a better addition*

S03-CUARO: *Most of the tasks are easy to understand to me, just sometimes I want to pause the video, but it ends when I tap the screen again. Overall it's cool.*

S04-CUARO: *The speed of the smartphone affected the application and I had to restart it.*

S05-CUARO: *I had to try and error to figure out how to rotate the 3d model with fingers.*

S06-CUARO: *The challenge I encountered is that the app makes my phone runs slower than usual.*

S07-CUARO: *None*

S08-CUARO: *As I have to read carefully to make sure and avoid any mistakes it took me some time.*

S09-CUARO: *I felt the need for new phone, it become slow as when I active “AR” in pokemon go option on this phone.*

S10-CUARO: *Since the application is not in play store I couldn't get around downloading it from google drive easily*

- Review of CUAR

S01-CUARO: *Easy to use application, the task were straight forward and I was able to execute them easily*

S02-CUARO: *I appreciate the enhanced version interactive learning provided by this application.*

S03-CUARO: *I like how we can get an Augmented Reality display by scanning an image relevant to the topic.*

S04-CUARO: *The AR part is great, I almost thought it was real for the COVID advertisement part.*

S05-CUARO: *It became very simple to use when you read the instructions.*

S06-CUARO: *Overall the application is easy to use and intuitive. I was able to perform all the tasks.*

S07-CUARO: *Easy to use, might need more functionalities like uploading trackers and 3d assets into the app.*

S08-CUARO: *If you follow the directions, anyone can achieve those tasks.*

S09-CUARO: *Great application, I enjoyed discovering what this technology can do other than pokemon go and Ikea AR app*

S10-CUARO: *Looks very good and well represented*

- **Suggestions for Improvement**

S01-CUARO: *I would say adding more buttons to control the video projects*

S02-CUARO: *According to me, adding video features such as rewind, pause, replay would increase the overall quality of the task.*

S03-CUARO: *Adding a pause function to the video would be nice. For the 3d model part, if it provides some more operations to interact with the model or animation in the model, it could be more interesting.*

S04-CUARO: *The would like all the buttons on one side of the screen and leave the other parts of the screen open for the viewing experience. Cool application overall!*

S05-CUARO: *Buttons can be more pronounced and better distinguished*

S06-CUARO: *Make it more suitable for previous generation phones*

S07-CUARO: *Optimization*

S08-CUARO: *This app will dramatically improve if runs more smoother*

S09-CUARO: *I would like to try it on my newer iphone instead of my old android*

S10-CUARO: *It's been challenging but I overcome it by reading the instructions.*

➤ **Pre-Service teachers' Group A participant's comments:**

○ Challenges encountered

PT01-CF: *I had to spend more time to learn how to use Augment application before i was able to see the results.*

PT02-CF: *1. Cuar feels a little less faster. 2. Augment feels like it needs more cognitive effort.*

PT03-CF: *I did not experience any difficulties.*

PT04-CF: *Cuar mobile app froze when I tried to take a screenshot.*

PT05-CF: *The Cuar website works well on my laptop, but the phone app works very slowly, making it difficult to use more than the other one.*

○ Review of CUAR

PT01-CF: *The CUAR application was easy and straight forward. This will help the teachers and the users accomplish their work more quickly and allow them to create more educational related content using the CUAR application.*

PT02-CF: *Very intuitive application for it's specific purpose*

PT03-CF: *I look forward to teaching topics using this application, having fun and learning simultaneously.*

PT04-CF: *Administrative web page is fantastic*

PT05-CF: *Good application but I'm not sure if it's because of my phone but that it needs some tuning.*

○ Suggestions for Improvement

PT01-CF: *A small pop-up box teaching the basic steps before using the application and on the website.*

PT02-CF: *Cuar needs to be more optimized.*

PT03-CF: *Adding more functionalities.*

PT04-CF: *Android optimization*

PT05-CF: *mobile app running speed and stability, I had to relaunch the app sometimes*

➤ **Pre-Service teachers' Group B participants comments:**

○ Challenges encountered

PT01-XF: *Cuar one is not as responsive as the other one, feel like it takes more time or even freez*

PT02-XF: *Not being enable to flip the 3D model.*

PT03-XF: *I tried to preview the 3d model I created using in both Augmented Reality both apps, but because of my 3d model choice, the 3d model didn't show as good as I wanted*

PT04-XF: *One challenge I encountered is that both apps run too slow in my relatively old phone. However, cuar stoped working one*

PT05-XF: *For both apps I needed a lot of time to perform the tasks, cuar took me less time but maybe because I used augment first so I became somewhat familiar with this technology*

○ Review of CUAR

PT01-XF: *easy to use and direct*

PT02-XF: *Very straight forward app, the other one has many more options which makes you wondering before founding what you are looking for*

PT03-XF: *Very good app, opens a lot of ways of teaching*

PT04-XF: *time It's clear and well represented not overwhelming*

PT05-XF: *It was really fun to use and see the 3d models on top of the paper. I see myself using it in classrooms in the future*

○ Suggestions for Improvement

PT01-XF: *make it faster and less laggy*

PT02-XF: *add a 3d models library where teachers can chose from.*

PT03-XF: *Login screen can be more responding*

PT04-XF: *Maybe should be more compatible with older phones*

PT05-XF: *cuar compared to the other one runs less smoother but more easy*

	Challenge	Suggestions for Improvement
S01-CUARO	-	Video Control Buttons
S02-CUARO	Unable to control the video player	Video Control Buttons
S03-CUARO	Unable to control the video player	Video Control Buttons
S04-CUARO	Performance Optimizations	Interface Improvements
S05-CUARO	3d Model interactions	Interface Improvements
S06-CUARO	Performance Optimizations	Performance Optimizations
S07-CUARO	None	Performance Optimizations
S08-CUARO	-	Performance Optimizations
S09-CUARO	Performance Optimizations	IOS compatibility
S10-CUARO	-	-
PT01-CF	-	Instruction as Pop-up
PT02-CF	Performance Optimizations	Performance Optimizations
PT03-CF	None	More functionalities.
PT04-CF	Performance Optimizations	Performance Optimizations
PT05-CF	Performance Optimizations	Performance Optimizations
PT01-XF	Performance Optimizations	Performance Optimizations
PT02-XF	3d Model interactions	Assets Library
PT03-XF	3D models compatibilities	Interface Improvements
PT04-XF	Performance Optimizations	Performance Optimizations
PT05-XF	-	Performance Optimizations

Table 8. Analyzed Summary of Participants' Open-ended Questions Answers

Discarded Statements	Reason
For some reason my phone just won't pick up the marker at the beginning but I tried to lower the brightness of my screen and it just worked	Marker is supposed to be on paper. Due to the ongoing pandemic, the experiment had to be done online, making the markers actually on the computer, not on paper.
As I have to read carefully to make sure and avoid any mistakes it took me some time.	A participant takes his time to read does not necessarily mean it is a challenge from CUAR
Since the application is not in play store I couldn't get around downloading it from google drive easily	The way participants downloaded the app is temporary due to CUAR being a prototype.
It's been challenging but I overcome it by reading the instructions.	Not being specific
I had to spend more time to learn how to use Augment application before i was able to see the results.	Augment related and not CUAR
Augment feels like it needs more cognitive effort.	Augment related and not CUAR
For both apps, I needed a lot of time to perform the tasks, cuar took me less time but maybe because I used augment first so I became somewhat familiar with this technology	Not being specific

Table 9. Discarded Open-ended Questions' Answer and Reason for Denial.

Appendix D : SUS Score Conversation Table (Sauro Jeff et al., 2018)

Grade	SUS	Percentile range	Adjective	Acceptable	NPS
A+	84.1-100	96-100	Best Imaginable	Acceptable	Promoter
A	80.8-84.0	90-95	Excellent	Acceptable	Promoter
A-	78.9-80.7	85-89		Acceptable	Promoter
B+	77.2-78.8	80-84		Acceptable	Passive
B	74.1 - 77.1	70 - 79		Acceptable	Passive
B-	72.6 - 74.0	65 - 69		Acceptable	Passive
C+	71.1 - 72.5	60 - 64	Good	Acceptable	Passive
C	65.0 - 71.0	41 - 59		Marginal	Passive
C-	62.7 - 64.9	35 - 40		Marginal	Passive
D	51.7 - 62.6	15 - 34	OK	Marginal	Detractor
F	25.1 - 51.6	2- 14	Poor	Not Acceptable	Detractor
F	0-25	0-19	Worst Imaginable	Not Acceptable	Detractor

Table 10. Percentiles, grades, adjectives, and NPS categories to describe raw SUS.

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