A new interaction experience in Extended Play at Faraday Museum

João Tiago Toscano de Azevedo Henriques
j.tiago.henriques@tecnico.ulisboa.pt

Instituto Superior Técnico, Lisboa, Portugal

January 2021

Abstract

Museums have knowledge to share, they are places to learn, that can teach us, about the past, present and make us think about the future. However, despite being increasingly interactive, museums are not making the most of the interactive potential they could have. These days, there is an opportunity to make the most of it, benefiting from new technologies such as Augmented Reality. Using Faraday museum, as an example, we try to solve this problem, by developing an Mobile Augmented Reality application, that captive and augment the museum artifacts. Following a User Centered Design approach, and a user experience methodology, the experience will be based on a try to learn approach, creating a interactive learning environment. The object chosen to augment is the Cathode Ray Object, that allows to control a electron beam (e-bean) by changing the electric and magnetic field. It will also be possible to interact with the object by the application, as well as to receive hints and explanations. This application is the continuation of the work of two IST students and has been successful not only within the heritage community of Lisbon University but between the potential users. We tested the application in terms of user experience, to evaluate its interface and game play, having very positive results.

Keywords: Augmented Reality, mobile application, interactive learning environment, User Experience

1. Introduction

Museums have knowledge to provide, they are places to learn, with immense potential to captivate people who want to know more. Unfortunately, There is a long way to go to introduce interactivity in museums, but this is a path that has to be taken as it brings value to them. Usually, it is forbidden to touch the pieces, even those that were created to be used, but today they are considered historical pieces, and the museum curators cannot let them be damage by the curiosity of the visitors. That's why visitors base themselves on walking around the museum, looking at the exhibits and reading the informative signs. To try to solve this problem at the Faraday museum[1], one of Instituto Superior Técnico (IST) museums, the "Extended Play at Faraday" thesis come up. This work was done by my colleague: João Barreto and a demo can be viewed in[2]. Luís Nunes, another IST student, took the work already done and continued its development, always aiming to improve the museum experience.

The general idea is to animate and allow the manipulation of Faraday museum objects, following an augmented reality (AR) approach with the objects as model target tracking systems. The final product is an AR mobile application. The game offers a set of challenges about museum artifacts, such as trying to fix them and understanding how they work. It also offers an enhanced view of the artifacts in operation, for example, showing the electricity or sound / radio waves.

The project has the collaboration of the Lisbon University Faculty of Fine Arts, one student from the Faculty designed and modeled the 3D object.

Most objects in the Faraday museum can be damaged to the touch, many of them are made of old wood and contain small, easily-breakable electronic parts. Although many museum objects are replicas, they are fragile and difficult to replace. The objects that are possible to interact, lack information on how to interact with them, and what they are for. Nevertheless, it is a museum where visitors learn a lot more by being able to interact and seeing how things happen, so it was necessary to find a way to improve the learning experience from the visitor's point of view.

This work was developed on top of my col-

[1] https://tecnico.ulisboa.pt/pt/tag/museu-faraday/, Last accessed in 12/12/2019

[2] https://www.facebook.com/LabJogosIST/videos/809006499491089/, Last accessed in 12/12/2019

leagues' work, with the help of Professor Moisés Piedade and Professor Carlos Ferreira Fernandes, the two directors and curators of the Faraday Museum. With their help we selected the Cathode Ray artifact. To augment the artifact, we added the new object in the already existing app and we continued the development. The application creates a learning environment, where the users can enjoy and learn while exploring the museum by explaining facts about the electromagnetism field. The application follows a responsive design, allowing to match several screen resolutions and orientations (Portrait or Landscape). We did several user tests to assure that the application developed accomplish our objectives. At the end of our work we hope to have improved the experience of this museum and helped other museums to follow in our footsteps and improve their experience.

1.1. Objectives

The main objective of this thesis is to improve the visitor experience by making it more interactive and fun, allowing a better learning experience. To accomplish these objectives, we continue the development of the AR Android app "Extended Play at Faraday Museum" which aims to improve the experience of the museum visitors.

To improve this app we have two goals:

- Augmented the Cathode Ray artifact from the Faraday Museum.
- Evaluate the work done so far by testing with users, changing any interaction problems found.

Furthermore, we intended that this work will be used as the basis of other possible works, in this museum or in others alike.

2. Related Work

Museums are learning places,, however there are some inherent problems that may not let them reach their full potential. Exhibition space, venues, schedules, inaccessibility and lack of interaction with the artifacts, that need to be protected, are some of the problems [14]. In addition, most of the information about the exhibited artifacts is usually passed to visitors by text on information panels, or by prerecorded audio tours [18].

2.1. AR in Museums

Augmented Reality (AR) has been explored as a solution to address the above-mentioned limitations. Altinpulluk et al. [2] conclude that AR can be used in Cultural Heritage (CH) applications, both in indoor and outdoor, and in different application areas, such as, exhibition, exploration and reconstruction of CH (as is illustrated in Figure 1).

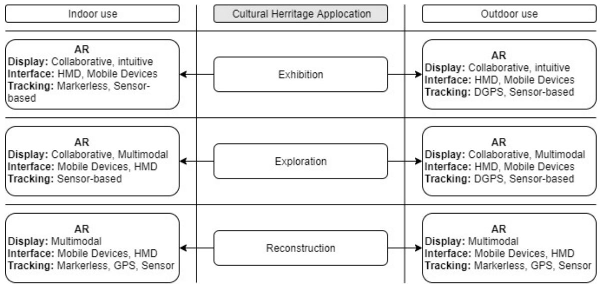

Figure 1: Different application areas of AR in CH, and the technical requirements of AR systems in indoor and outdoor settings, according to Bekele M. [7].

Altinpulluk et al. [2] also conclude in their study that most of the AR museum applications are used in indoor exhibitions, using mobile devices as display and, typically, with three types of tracking systems:

- Marker-based: that use 2D special visual symbols like images (image target) or QR codes, to track the camera position [7]. As an alternative a 3D model of a real object (model target) can be used as well. [2];
- Markerless: using geometric features in the real environment by detecting and recognizing them, to track the camera position [7];
- Sensor-based: that use sensor data for tracking. these can be divided in different types of tracking depending of which sensors are used. Being the most common the Inertial Tracking, that uses Gyroscopes and Accelerometers [7].

From the point of view of Altinpulluk et al.:"...what emerges in the main is the need for curators to provide users with a new perspective on their collections. Museums, for example, can increase their appeal by augmenting their artifacts or paintings with digital media". They pointed out further that besides the AR capabilities, there are still some hurdles that prevent the acceptance of immersive technologies in museums. These are due mainly to technological limitations, the complexity of content, and human factors of the experience.

Xueai Li et al. [17], developed a serious game based on AR, using Tsingtao Beer Museum as a case study. The game aimed at improving issues with visitors of the museum that got easily lost, and had a hard time understanding how the machines displayed work. The user studies performed showed that the AR game added joy to the visits and improved the immersion and experience of visitors. These authors conclude that the use of AR games may bring great benefits to museums, attracting more visitors and increasing the sales of souvenirs.

Kyriakou et al. [14] combined AR with natural interaction, using model target tracking, to grant the ability to visitors of interact virtually with inaccessible cultural heritage artifacts in the displays. Their user experience tests, showed that to explore digital 3D replicas of the artifacts in the museum was well accepted by the visitors.

Similar benefits were found by the Heinz Nixdor museums Forum at Paderborn that used a AR app using a tracking system based on markers [9].

Ryffel et al. in [26], developed an AR mobile application using image target tracking, and explored the use of simple touch interaction, for museums and art exhibitions. Highlighting the potential of natural interactions combined with AR.

The ARtLens [24] AR app, for the Microsoft HoloLens, that also uses model target tracking, enables museum visitors to actively interact with the artifacts as well and facilitating learning about the artifacts through this interaction. The application was successful, but the authors discuss the importance of not distracting the visitors from seeing the original artifacts.

The AR-Muse project [19] also show potential benefits of AR in retention and transfer for learning in art museums.

2.2. Extended Play at Faraday Museum

As explained in Introduction, this thesis will continue the work done by João Barreto and Luís Nunes. João Barreto [5] [6], developed the first version of the application "Extended Play at Faraday Museum", a serious game application for people with twelve years old or more. He decided to use Unity with Vuforia, and model target with 3D CAD model as tracking system. Model target, in a simplified way is a tracking system, that compares the 3D model with the objects that device camera captures. When there is a match, triggers the application to show the AR object in the device. From the tests done by João, this is the most precise system, however needs a good device, since this comparison happen multiple times by second. The object animated was a Gower-Bell Telephone, this object was chosen because it is an iconic artifact of the museum, and visitors don't really understand how it works. From the user's test made he concluded that on average, there was an increase of 49% of the right answers about the object, compared to people who did not use the application. Figure 2 shows a image of the Gower-Bell Telephone in the AR application.

The experience of using the application is entirely done in the device, i.e., there is no interaction between the user and the artifact. Yet the users found it interesting and helped them to understand the object better. Luís Nunes improved

Figure 2: Gower-Bell Telephone in AR.

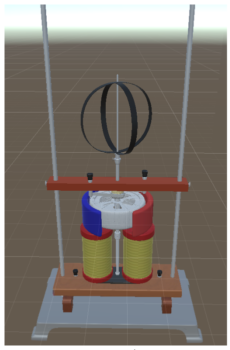

Figure 3: Dynamo\Engine in AR.

the work done by João and developed a new interaction with a different object. The object chosen was Dynamo\Engine that allows interaction with the parts of the object, and with the app. The app also give hints, explains the concepts and allows to visualize the electric field direction and the magnetic field. The thesis of Luís is still in progress. Figure 3 shows a previsualization in Unity, of the Dynamo\Engine in the AR application.

2.3. AR for Education

Museums have the goal to educate their visitors. But the exhibitions tend to explain the objects with a text panel beside the object or in prerecorded audio tours. These types of explanations create some distance between the object and the visitor, besides that, they are not the best way to educate the user [18]. Since AR can fill the gap of museums that do not offer enough interactive content [18], and according to Wu et al. [2] [28], AR in educational settings has the potential to provide content in a three-dimensional perspective, to create simultaneous and collaborative learning opportunities, to make the invisible to visible, and to bridge formal/informal learning [2] [28]. So, it is important to understand how, and if we can use AR for learning purposes.

According to our research, it is possible to conclude that one of the best ways to learn is learning by experience. A practical based learning takes advantage of trail and error to build knowledge from previous mistakes [1] [16] [20] [22]. Stewart 2014

[22] also says that to be an effective learner it is necessary to be involved, focused, spend time and work, and be mindful of challenging activities. According to his studies [15] [16] digital technologies, and mobile in particular, can help students in learning due to the fact that they enable the learning process to be done at any time and place, and in a continuous way. Andre et al. [3], focus their work on how museums can help children learn, and says that museums that integrate technology and activities in their exhibitions, can positively influence children's' behaviour in discussion and exploration of the exhibits, as well as influence the critical thinking, create curiosity, excitement and memorable moments. Andre et al. also argue that experiential learning experiences can benefit from using AR technology.

Morentin et al. in [21] remind us to the fact that many primary schools try to make field trips to museums because they are considered a powerful learning resource given their recreational and educational potential. Thee authors also say that museums are ideal environments for facilitating children's experiential learning.

Museums will benefit with the AR experience from a educational point of view as well, since AR can create interactive learning environments, that will captivate, motivate and provide learning experiences, while the user is engaged and willing to make an effort to learn. AR is a great tool to use in experiential learning.

2.4. User Experience in AR

To create this study was important to research how Mobile Augmented Reality (MAR) application are tested. In this section we will review the methods used for test MAR applications.

Although User Experience (UX) is widely accepted in web design, there is still some reluctance to use UX in MAR, Arifin et al. [4] attributes this problem due to the ease of developing AR by non-professionals.

The International Organization for Standardization (ISO) defines UX as "a person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service"[12]. UX is fundamentally subjective, it changes according to users and their experiences, as well as the time they experience the product [11]. UX is generally described as an umbrella term for planning, assessing and examining the encounters that user feel while utilizing any item, system or service in a specific setting [25].

UX can measure, in a qualitative or quantitative way, different aspects of an application, such as functionality, reliability, usability, efficiency, maintainability, portability and aesthetics [11] [29]. The metrics used to evaluate these aspects, depends on which aspect you want to measure, the type of application and the context. According to Zaid et al. [29], the most used methods to evaluate usability are heuristic evaluation, cognitive walkthroughs evaluation, conventional user test, laboratory testing, and field testing. For the techniques Zaid et al. suggests: Observation, Think-aloud, Audio / Video recorder and semi-structured interview, or a combination of them.

In terms of user tests, they can be divided in two groups: Laboratory Tests and Field Tests. The Laboratory Tests, usually, are tests where the user is in a peaceful environment, where the developing team is next to the user taking notes of what is happening and helping if needed. The environment, and the methods used can depended of what is being tested, i.e., an app, game, website, etc. But usually tries to imitate the real environment where the product will be used. The Field tests, as the name implies, are tests that occurs in the location where the product is going to be used, this tests normally don't have a team helping next to the users, but the developing team is accessing the data in real-time and improving the product as the users use it [8] [13] [23].

Altınpulluk et al. in[2], concluded that surveys, Tests, interviews and observation are the most common tools to collect data from the users. We also concluded that we can test different things from our application, with different methods and techniques. There is not a "fit all" solution. One important thing to retain is, before test with users, we should define our research questions (RQ), serving as a basis for everything else, i.e., we should choose the methods and techniques to test, based on our RQ [10] [19] [29] [30].

2.5. Mobile Applications in Museums

According to Henry Tsain [27], museums are at the forefront of adopting mobile technology to enhance visitors' experience. From this point of view, is important to allow a customized visit, for that Tsain suggest four ways: customized tours, wayfinding, bookmarking and social media technology.

In addition to that, there are several ways to enhance the interaction and learning: Multimedia tour, Augmented reality and Casual Games.

The author also highlighted the importance of that communication and social interaction between visitors, as well as interaction with the exhibits, are key to building a successful museum learning experience.

The above arguments reinforce our approach of using a playful AR mobile application to improve the experience of visiting a museum. We can also withdraw some additional features that our application may have, like, bookmarking and social media technology.

3. Implementation

During the development of this thesis, we participated in different activities and performed different works with the objective of improving the visiting experience of the Faraday Museum. We can highlight the Technical Report[3], where we document our work and guide the next developer in add/maintain important features of the app. Faraday Museum dissemination's where we could understand better how the visitor walks and interacts in the museum, as well validate the conceptual idea of the project and the actual development of the Faraday Museum app. That we will explain on this section.

3.1. The psychics behind the Cathode Ray

To allow the user to change the e-bean, we need to be able to calculate the shape of the e-bean with values given by the user.

There are three values the user can change, that are: intensity, tension and the rotation.

To implement this, we used the formulas calculated by Professor Carlos Fernandes, that allows to calculate the magnetic field and what shape is taking form by the given the given values. It also allows to draw the format of the shape.

3.2. The e-bean draw

In our Cathode Ray we can make 3 shapes: Lines, Circumferences and Spirals. To draw these shapes in our game, we researched in what ways we could draw them. Since, in programming is always possible to accomplish the same objective by different paths. We decided that the best two ways were: the Line Render component or the Particle System.

We decided to use the Line Render, since this is more efficient, it's able to draw the entire shape in a frame, and if the values don't change we don't need to redraw. The line render also allow us to better control what we are drawing.

The Line Render in a simple way, is a component where you define the points by coordinates, and by itself calculates the interpolation between them, connecting the points by a line. So, with two point we get a line between them, with 360 points in a circle path, we get a circumference.

To modulate the e-bean we created a basic blue material, since this is the color of the e-bean in our Cathode Ray.

The e-bean in the Cathode Ray, has a "limitation", when the e-bean touches the glass, it loses its strength, and disappears. So, we can't see the whole spiral, or the whole circumference if this has a radius bigger than the ampule. So, we "augmented" the e-bean, i.e., instead of stop drawing the e-bean when it touches the glass, we draw, with a different color. To find the perfect color, we did different tests by sending the same shape with different colors to some friends, through social networks. In the end the color chosen was the same color as the e-bean but more transparent.

Figure 4, shows a spiral with a fade blue e-bean, representing the part that is not visible in real life.

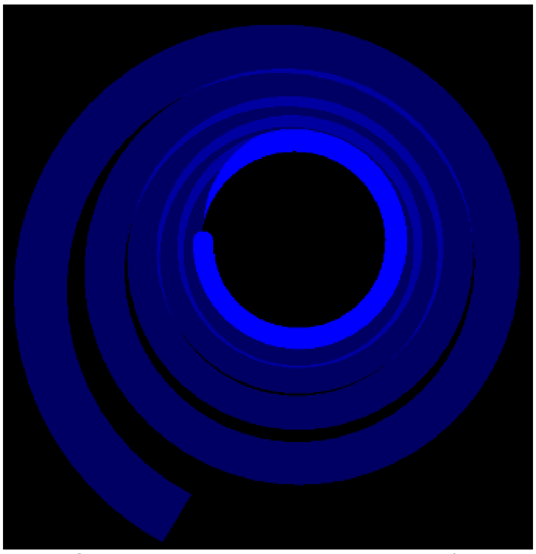

Figure 4: Spiral, Intensity = 1.5 A, Rotation = 100º, Tension = 100 V.

To create this fade line, we had to implement a shader. Because, in AR the position where we start drawing is relative, and constantly changing, since it's complicated to keep your hands 100% in the same place. And, Unity doesn't support collisions between visual effects (the line render component) and 3D elements (the ampule). Also, shaders are a really strong way to make powerful visual effects in a very efficient way, since it runs in the Graphics Processing Unit (GPU).

To make the shader work, we pass the radius of the ampule, the two colors, and the position of the ampule. After that we calculate for each point of the e-bean if it's inside the ampule or not. If not we change the color to the fade color. In a simple way, this shader works as a force field, everything inside the force field, has one color, everything outside the force field has another color. But, as this shader is only added to the e-bean material, it only affects the e-bean, i.e., when we added the Cathode Ray 3D model, it will not be affected.

However, this shader has a problem, in the case of the circumference there are always two parts of the e-bean inside of the ampule. Contrary to what should happen, that if the e-bean touches the glass never comes back in the ampule, that is, the sec-

[3] https://github.com/Toscan0/IST-Thesis-FaradayMuseum/blob/main/Project/Technical%20Report.pdf, Last accessed in 27/11/2020

ond part of the circumference should be all with fade blue color. For that, we calculate the point where the circumference touches the glass, and start to draw it with the fade blue color.

3.3. Android User Interface

Taking into consideration, that at this time, the app will not be available to the users to download. So, we can specifically aim the museum' tablets, that has resolution: 2560x1600. However, we did a responsive interface, that resizes with the screen resolution, and position: landscape or portrait. The only constrain is if the user uses a bigger screen the will have a lot of empty space, or if uses a smaller screen everything will be clustered.

Taking into consideration that people need to use at least one hand to hold the tablet in position and the other hand to play. We need to put anything that is interactable near the left and right edges. So, according to this, we made the buttons on the left side, and the control panel on the right side. The pop-ups occupying the entire bottom side, which allows the users to have the arrows to change between pop-up on each respective side. The hint appears on the top side, since it is in a more difficult position to be closed, it closed by itself after a while. These changes are possible to see in the Figure 5.

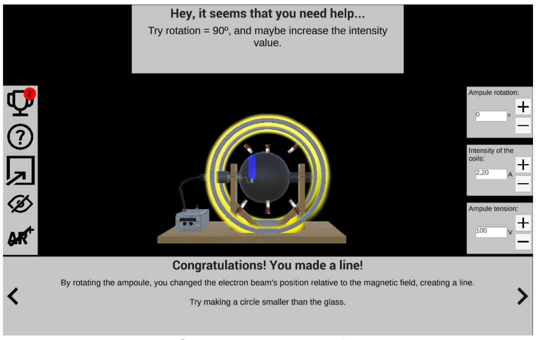

Figure 5: Second version of Android UI.

In Figure 5, the background is black, because we are simulating the AR, i.e., in our case, we are simulating the scan of the Cathode Ray image target. When used in the Android environment, it will show what the camera's device captures. The buttons from top to bottom allows the user to: view the achievements, the instruction, close or open the pop-ups, disable / enable the static parts of the object, disable / enable the electric and magnetic augmentations as well as the augmented part of the e-bean. The augmentation of electricity it's basically an yellow circle rotating around the coils, than increase / decrease the thickness according to the intensity. Giving a visual representation of the direction and strength of the electric field. For the magnetic field, we use an already existing representation on the app, for consistency reasons.

It is also, possible to close the pop-ups just by clicking on them. A technique used by many mobile games, such as Archero.

Since an abnormal use of our app, may be the user constantly touch the intensity values very quickly, causing a large variation of the blue light beam, we add a warning Photosensitive epilepsy[4]. To create the warning we follow some examples such as the PlayStation health warning[5]. This warning was also added to the WebGL version.

3.4. Bluetooth

To be able to receive data from the artifact, we are going to use a BLE device (hm-10 module, cc2541 chip Texas Instruments[6]).

We decided to use BLE instead of Bluetooth since BLE doesn't require to connect the mobile device to the Bluetooth device. This makes possible to use several BLE devices in the application without the need for the user to connect to each Bluetooth device when needed. With the BLE the connection and disconnection is handled by our application.

In the Cathode Ray artifact, we receive 3 things from the BLE device: the tension, the intensity and the rotation of the ampule. After this we process the information, and we calculate the necessary information to draw the respective figure.

Our idea was also to be able to send the data through Bluetooth to the Cathode Ray and to have a mechanism that changes it. However due to COVID-19, the necessary changes in the artifact to make this happen, and the Bluetooth device are still in progress, so we didn't implemented this.

So, since we can't change the Cathode Ray by Bluetooth, we can't allow the user to use our interface to change the values when connected to the object. Since, it would not make sense, to have different values in the app and in the artifact. So, for this reason, if the user is connected to the Bluetooth device the buttons to change the value are hidden, however we still show the values to the user, so we can see what values is he changing in the Cathode Ray artifact. The user can choose if is connected or not to the Bluetooth by pressing the respective button.

However, we couldn't test this in the museum with their BLE device, we tested with an homemade Arduino and it worked fine.

[4]https://www.epilepsysociety.org.uk/photosensitive-epilepsy, Last accessed in 12/10/2020

[5]https://www.playstation.com/en-us/network/legal/health-warnings/, Last accessed in 12/10/2020

[6]http://www.ti.com/product/CC2541, Last accessed 14/04/2020

3.5. User interaction recording System

To be able to store information about user interactions with the game, like clicks, drags, objectives completed, timestamps, etc. We had to create a User interaction recording System. We created the system, using UnityWebRequest and the IST web server, which is located on our personal page.

This server it's public access and should be used only for interaction data, no personal information is should be kept. To kept the user anonymous, the name file is given by the time stamp and 14 random numbers.

4. Results

These user tests were done in the IST' Faraday Museum, with the objective of evaluating our application, in terms of interface design, ease of use, efficiency, stimulation and understanding, and identify possible stress points of our application. The test also had the objective to see how the user uses our application, in terms of body posture, how they hold and interact with the tablet.

Anyone can be a potential user, the only requirement to participate in the test is understanding English.

To create awareness of the test and contact potential users, we posted in several IST Groups, a short text explaining the concept of the app, and asked them to test our app. Due to COVID-19 limitations, we asked them to send an email to us, to reserve an hour for the test. The test was only advertised within the IST community, as it is necessary for users to go to the museum.

The users need to go through all of the objectives in the app to be able to answer the questionnaire, and at the end a button appears asking them to answer the questionnaire with the following structure:

- The first section had a text explaining the form, and saying that the data will be treated anonymously, and had the ID placeholder;
- The second section had demographic questions (Genre, Age, Academic Qualifications);
- The third section had questions from the User Experience Questionnaire (UEQ);
- The fourth section asked was the worst and the best part of using our application;
- The fifth section thanked users and allowed them to leave extra feedback if they felt it was necessary.

The test followed the Think-aloud methodology, that is, the users talk about what they are thinking and trying to do while we listen and watch them using the application, taking notes. Without helping the user.

The results of this text, are presented in the following Subsection 4.1

4.1. Discussion or Android Evaluation Results

We tried to gather people to test our app, during two weeks. We were able to gather 20 users, of which 50% were male. 80% of the users are aged between 19-25 and 20% between 26-40 years old. In terms of Academic qualifications, 45% has Bachelor's degree, 35% Master's degree and with both 10% PhD and 12th grade / High School.

From the UEQ section in our questionnaire, we obtain the following results. Regarding each point, the results were very good, the lower value, with a mean on 0.6 was the "predictability" of the app, however, it's normal the user can calculate what is going to happen next, since this is an AR app of a physics experience. In the most important points for us: enjoyable, understandable, valuable, supportive, good, easy, efficient, friendly. We had extremely good results.

In the 6 scales rated by the UEQ we also had very good results, regarding Pragmatic Qualities and Hedonic Qualities the results were good, it is possible to see in Figure 6 and Figure 7 respectively.

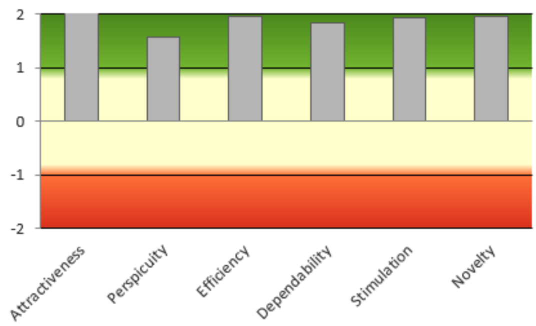

Figure 6: Android UEQ results relative to the scales Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, Novelty. (Red- bad, Yellow- Average, Green- Good).

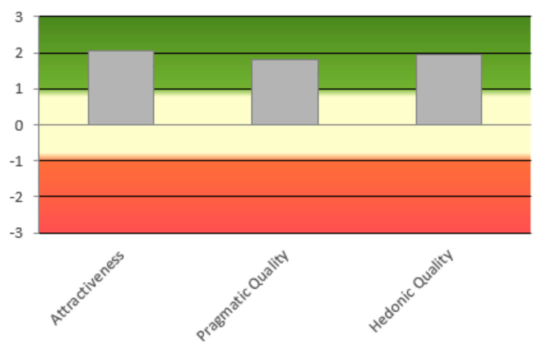

Figure 7: Android UEQ results relative to Attractiveness, pragmatic quality and hedonic quality.

Regarding how much we can trust on this values, the Table 1, show us the confidence intervals, were all of them are lower than 0.5%, meaning that all of them are very small and trustful.

Table 1: Android confidence intervals (p=0.05) per scale.

Scale	Conf.	Conf. interval	
Attractiveness	0,344	1,723	2,410
Perspicuity	0,497	1,078	2,072
Efficiency	0,361	1,601	2,324
Dependability	0,363	1,475	2,200
Stimulation	0,373	1,552	2,298
Novelty	0,354	1,608	2,317

In the open-ended questions, 13 users answered the question relative to identify the worst part of using the app. The majority, answered relative to the necessity to holding the tablet in place to scan the object, and that sometimes the 3D model of the object was shaking, and not in the correct position. A couple of users referred that at first they couldn't understand what to do, and that the explanations were not clear enough. 17 users answered the question relative to identify the best part of using the app, the majority answered regarding the fact that it is an AR app, that is funny and innovative, and that made it possible to view the object and augmented representations of reality. A few users commented the fact that were able to learn something new, and that the UI was well accomplished, and that the hints help when the user is stucked.

In relation to the UI, one user said: "The interface is well designed, uniform and with all the necessary functionalities to work correctly".

From what we were able to see from the user behaviour, the users prefer to use the tablet in landscape orientation. All users, had no problem in realizing that it was to point at the object to scan, but some thought that after the scan they hadn't to keep pointing, but quickly realized that they had. Regarding of interaction gestures, some users hold in both hands and interact with the thumbs, others hold in one hand and interact with the index finger of the other hand, and few of them hold with the left hand and only interact with right hand, even if the interaction is in the left side. To rotate the ampule a few users tried to rotate by gesture, i.e., to rotate the glass of the 3D model. A few of them, also tried to increase and decrease faster by holding the button. Only a couple of users understood that they could move around and get closer or further to see the object from different points-of-view, however there was an explanation alerting them to this fact.

In our opinion, this results are extremely good, they go according to what we wanted. Users have shown that they can learn and have fun at the same time, using our app. They shown great interest in trying an AR app and trying to take full advantage of that. However, a few users didn't try to move around, we think this is because AR is not a mature technology in the market, and a lot of people are not yet used to it. The users also gave a lot of positive feedback to our UI, and mechanism implemented in the game, to help the user going through. However, a few users had problems in the initial phase of the game, and didn't understand the explanation, showing that this can be a stress point as it was also detected in the WebgGl test, that were not changed before to gather more feedback about this problem. According to the feedback received, we are going to change the explanations to improve even more the usability of our app. Holding the button to increase or decrease the values are also a great feature they will be taken in consideration in the development phase.

Regarding the users that pointed out that holding the device in place for being able to play is not a good thing we can't do much, this is how AR is supposed to work. Without the constant scan it would be only a normal app, where the users could interact with the mobile but not with the world, and the world would not have impact in our app. The only options to lessen this problem, are to deploy the app in the app store, so the users can use their mobile phone that are more used to it or to arrange some physical support that hold the tablet, but allows the user to explore the museum with the tablet. The shaking image can be deviated from different reasons, among them, the person's hands shaking, little light in the room, an angle or distance from the object that the 3D model cannot orient itself, poor quality of the tablet camera or a bad 3D model. We will address more time in future to try to find the origin of this problem.

Nevertheless, all the users seemed to enjoy our application, and that was the principal objective, that now is completed.

For scientific transparency reasons, all the data collected in this study can be accessed here[7].

5. Conclusions

This Thesis had the objective of improving the visitor experience by making it more interactive and fun, allowing a better learning experience. For that we improved the AR Android App- "Extended Play at Faraday Museum" by adding an augmentation of the Cathode Ray artifact and improving the organization and readability of the work already done. We also created easy ways of implementing several things. These improvements will facilitate the work of the next developers. Due to, COVID-19 we had some difficulties in testing and developing our

[7] https://github.com/Toscan0/IST-Thesis-FaradayMuseum/tree/main/UserTests%20Data/AndroidTests/, Last accessed in 25/11/2020

application around the user opinion, however we were able to overcame them by creating an WebGL app.

In the tests done, we had extremely good results, were the users showed a lot of interest in our app and understand our UI. From the tests we can concluded that our app is fun, interesting and helps the user enjoying the museum. Thus, we can state that we complete the objectives defined for this thesis.

At the end of this work, we delivered, in addition to this document, an WebGL version that can be used as a base to an online or Virtual Reality Museum, an Image target and Model Target version of our app, both in English and Portuguese. We also delivery a Technical Report with documentation of the work and a Wiki&How section and a GitHub Repository[8] with all the work done.

We hope we have improved severely the visiting experience of the museum, and that when it will be possible to visit museums again, visitors will appreciate our work and motivate them to visit the museum. We also hope that our work, motivate others to do the same, since our tests proved that is a value asset.

6. Limitations and Future Work

We are very proud of the work accomplished, but the work contains a few limitations:

- The Cathode Ray artifact is supposed to work on a dark room, however this was not covered in our development, due to the fact that the artifact was not working;
- However our UI is very responsive, may not work very well in very small our large screens.

In the next list we present the future steps of this work:

- Calculate the thickness of the e-bean;
- Test the BLE connection with the museum module;
- For user customization reasons: allow the user to select the level of expertise in the electromagnetic field, and change the explanations according to that;
- However, the UI is friendly enough, it is possible to foresee some problems for older users to hold the tablets in the right place during the whole experience;
- 2D ArtWork documentation: For a better consistency between the user interfaces of each developer, is necessary to create a documentation of the ArtWork present on the thesis, with the fonts, images and textures used and a description when and how to use them.

[8] https://github.com/Toscan0/IST-Thesis-FaradayMuseum/, Last accessed in 25/11/2020

References

[1] M. S. Abdusselam and E. T. Güntepe. Augmented reality: Educational Resources. *Augmented Reality for Enhanced Learning Environments*, (March 2019):1–24, 2018.

[2] H. Altinpulluk. Determining the trends of using augmented reality in education between 2006-2016. *Education and Information Technologies*, 24(2):1089–1114, 2019.

[3] L. Andre, T. Durksen, and M. L. Volman. Museums as avenues of learning for children: a decade of research. *Learning Environments Research*, 20(1):47–76, Apr 2017.

[4] Y. Arifin, T. G. Sastria, and E. Barlian. User Experience Metric for Augmented Reality Application: A Review. *Procedia Computer Science*, 135:648–656, 2018.

[5] J. Barreto, P. Gouveia, and R. Prada. Extended play at faraday museum. In *VJ2018 — 10th Conference On Videogame Science and Arts*, 2018.

[6] J. Barreto, P. Gouveia, and R. Prada. Jogo de realidade aumentada para o museu faraday. Master's thesis, Instituto Superior Técnico, Portugal, Lisboa, 2018.

[7] M. K. Bekele, R. Pierdicca, E. Frontoni, E. S. Malinverni, and J. Gain. A survey of augmented, virtual, and mixed reality for cultural heritage. *Journal on Computing and Cultural Heritage*, 11(2), 2018.

[8] B. Elliott, J. Alderson, and E. Denver. Field versus laboratory testing in sports biomechanics: System and modelling errors. 07 2006.

[9] M. Grafe, R. Wortmann, and H. Westphal. AR-based interactive exploration of a museum exhibit. *ART 2002 - 1st IEEE International Augmented Reality Toolkit Workshop, Proceedings*, 2002.

[10] R. Harrison, D. Flood, and D. Duce. Usability of mobile applications: literature review and rationale for a new usability model. *Journal of Interaction Science*, 1(1):1, May 2013.

[11] S. Irshad, D. Awang Rambli, N. Adhani, S. R. Mohd Shukri, and Y. Omar. *Measuring User Experience of Mobile Augmented Reality Systems Through Non-instrumental Quality Attributes: 5th International Conference, i-USEr*

2018, Puchong, Malaysia, August 28–30, 2018, Proceedings, pages 349–357. 01 2018.

[12] ISO. Dis 9241-210 (2010): Ergonomics of human system interaction – part 210: Human-centered design for interactive systems. Technical report, International Organization for Standardization, Geneva, Switzerland., 2010.

[13] T. Kallio, A. Kaikkonen, et al. Usability testing of mobile applications: A comparison between laboratory and field testing. *Journal of Usability studies*, 1(4-16):23–28, 2005.

[14] P. Kyriakou and S. Hermon. Can I touch this? Using Natural Interaction in a Museum Augmented Reality System. *Digital Applications in Archaeology and Cultural Heritage*, 12(July 2017):1–9, 2019.

[15] C.-H. Lai, J.-C. Yang, F.-C. Chen, C.-W. Ho, and T.-W. Chan. Affordances of mobile technologies for experiential learning: the interplay of technology and pedagogical practices. *Journal of Computer Assisted Learning*, 23(4):326–337, 2007.

[16] C. H. Lai, J. C. Yang, F. C. Chen, C. W. Ho, and J. San Liang. Mobile technology supported experiential learning. *International Journal of Instructional Media*, 36(1):41–54, 2009.

[17] X. Li, M. Xie, and J. Chu. Exploring the Application of Serious Game Based on Augmented Reality: A Case Study on Tsingtao Beer Museum. *IOP Conference Series: Materials Science and Engineering*, 573:012069, 2019. IOP Conference Series: Materials Science and Engineering.

[18] Y. C. Li, A. W. C. Liew, and W. P. Su. The digital museum: Challenges and solution. *Proceedings - ICIDT 2012, 8th International Conference on Information Science and Digital Content Technology*, 3(March):646–649, 2012.

[19] W. Lu, L. C. Nguyen, T. L. Chuah, and E. Y. L. Do. Effects of mobile AR-enabled interactions on retention and transfer for learning in art museum contexts. *ISMAR 2014 - IEEE International Symposium on Mixed and Augmented Reality - Media, Arts, Social Science, Humanities and Design 2014, Proceedings*, pages 3–11, 2014.

[20] N. Moorhouse, M. C. tom Dieck, and T. Jung. An experiential view to children learning in museums with Augmented Reality. *Museum Management and Curatorship*, 34(4):402–418, 2019.

[21] M. Morentin and J. Guisasola. The role of science museum field trips in the primary teacher preparation. *International Journal of Science and Mathematics Education*, 13(5):965–990, Oct 2015.

[22] S. N. *"Active Learning." In Characteristics of Effective Early Learning: Helping Young*. Maidenhead : Open University Press, 2013.

[23] A. Oztoprak and c. Erbug. Field versus laboratory usability testing: A first comparison. 01 2008.

[24] C. Pollalis, A. Gilvin, L. Westendorf, L. Futami, I. Virgilio, D. Hsiao, and O. Shaer. ARtLens: Enhancing museum visitors' engagement with African art. *DIS 2018 - Companion Publication of the 2018 Designing Interactive Systems Conference*, pages 195–200, 2018.

[25] V. Roto, E.-C. Law, A. Vermeeren, and J. Hoonhout. *User experience white paper: Bringing clarity to the concept of user experience*. s.n., 2011. geen ISBN Result from Dagstuhl seminar on demarcating user experience, sepember 15-18, 2010.

[26] M. Ryffel, F. Zünd, Y. Aksoy, A. Marra, M. Nitti, T. O. Aydin, and B. Sumner. AR museum: A mobile augmented reality application for interactive painting recoloring. *Proceedings of the International Conference on Interfaces and Human Computer Interaction 2017 - Part of the Multi Conference on Computer Science and Information Systems 2017*, (c):54–60, 2017.

[27] K. Sung and H. Tsai. Mobile applications and museum visitation. *Computer*, 45(04):95–98, apr 2012.

[28] H.-K. Wu, S. W.-Y. Lee, H.-Y. Chang, and J.-C. Liang. Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, 62:41 – 49, 2013.

[29] B. Zaid, R. Jamaludin, and B. Wafaa. A comparative study of usability methods for mobile applications. *International Journal of Scientific & Engineering Research*, 3(8):1–4, 2012.

[30] D. Zhang and B. Adipat. Challenges, methodologies, and issues in the usability testing of mobile applications. *International Journal of Human–Computer Interaction*, 18(3):293–308, 2005.