# A new interaction experience in Extended Play at Faraday Museum

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# 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, museum, User Experience, Unity, Vuforia

# Resumo

Os museus têm conhecimentos a partilhar, são lugares para aprender, que nos podem ensinar, sobre o passado, o presente e fazer-nos pensar sobre o futuro. No entanto, apesar de serem cada vez mais interactivos, os museus não estão a aproveitar ao máximo o potencial interactivo que poderiam. Hoje em dia, há uma oportunidade de aproveitar ao máximo, beneficiando de novas tecnologias como a Realidade Aumentada. Usando o museu Faraday, como exemplo, tentamos resolver este problema, desenvolvendo uma aplicação móvel de Realidade Aumentada, que cativa e aumenta os artefactos do museu. Seguindo uma abordagem de Design Centrado no Utilizador e uma metodologia de experiência do utilizador, a experiência será baseada numa abordagem de aprender fazendo, criando um ambiente de aprendizagem interactivo. O objecto escolhido para aumentar é o Raio Catódico, que permite controlar um feixe de electrões (e-bean) através da alteração do campo eléctrico e magnético. Também será possível interagir com o objecto através da aplicação, assim como receber dicas e explicações. Esta aplicação é a continuação do trabalho de dois estudantes do IST e tem tido sucesso não só no seio da comunidade de preservação da cultura da Universidade de Lisboa, mas também entre os potenciais utilizadores. Testamos a aplicação em termos de user experience, para avaliar a sua interface e jogabilidade, tendo tido resultados bastante positivos.

# Palavras Chave

Realidade Aumentada, Aplicação Móvel, Unity, Vuforia, ambiente de aprendizagem interativo, Experiência de utilizador

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# 1

# Introduction

## Contents

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 are considered historical pieces, and the museum curators cannot let them be damage by the curiosity of the visitors. That's why often museum visits 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 system. 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 and 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 colleagues' 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. Although it is possible to interact with it, is complicated to understand how and what is happening. With this app we intend to solve these problems, involving the user in a fun and learning environment.

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

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[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

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.

## 1.2   Organization of the Document

This thesis is organized as follows: Chapter 1 where we introduce the work and define the objectives. In chapter 2 we present the Related Work. In chapter 3 we define our solution to the problem present here. In chapter 4 we present the disseminations done. Chapter 5 we describe the WebGL work done and in chapter chapter 6 its evaluation. Chapter 7 we describe the Android work done and in chapter chapter 8 its evaluation. In Chapter 9 we present the conclusion of our work.

# 2

# Related Work

## Contents

Since Augmented Reality (AR) have appeared, more and more companies have been using this new technology to solve user experience problems. Augmented Reality is defined by Azuma (1997) [2] as "a system that combines real and virtual content, provides a real-time interactive environment, and registers in 3D". According to Bekele et al. [1] [3], AR completes reality without completely replacing it. This means it can be useful for providing extra information, it is also used to put scenes into context and highlight contrasts with the current reality.

## 2.1 AR in the world

Augmented reality is being used for everything since medical training to entertainment properties. The need for a small investment to have a good application is one of the main factors for its success, and people seems to receive these new technologies with open arms. There are a lot of examples of successful AR, let's look at some solutions that uses Vuforia. 4D anatomy[1], was developed with the aim of helping to study the human body allowing to see a human body from inside, i.e., the muscles, the bones, the nerves, etc. Interior Designers[2] are using AR to visualize rooms inside houses and be able to decorate it, like it was a dress up game, and being able to see the final product and show it to the client. Big Bird's Words[3] is a educational game for Preschoolers kids. There are also Advertising Companies using AR to Make Advertisements by Pointing the Cell Phone at some objects[4]. INDE created an AR system[5], where is possible to visualize in a screen, the real-world and a alien. This alien is motion and voice controlled by an actor, being possible to interact with the audience. In the advertising industries, AR is used to display digital content on top of real-world magazines.

According to the study made by Altinpulluk et al. [4], AR's popularity has been increasing. AR applications are mostly used for improving learning performance, and normally used in a tablet or smart phone. Museums appears at the six mostly common environment for researches with AR, being the most common classrooms. From this study we can notice the importance of AR used in educational environments, and that tablets and smart phones are good displays to interact with AR. We can also see that some investigations were carried out in museums. According to Bekele et al. [1], the essential aspects of AR applications are:

- Tracking and registration;

- Virtual environment modelling;

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[1] https://www.youtube.com/watch?v=Bq8R3-KmlJ0, Last accessed in 27/12/2019
[2] https://www.youtube.com/watch?v=O-8ObxUN-pk, Last accessed in 27/12/2019
[3] https://youtu.be/8DnCHGFKa7s?list=PLrCBNJga3kdFtsO4EMG9W25jSO7219HRX, Last accessed in 27/12/2019
[4] https://www.youtube.com/watch?v=LBLwe8FE_o4, Last accessed in 27/12/2019
[5] https://www.youtube.com/watch?v=AjY-QNHEvP8, Last accessed in 27/12/2019

- Computers, display, and devices for input and tracking;

- Interaction interfaces.

From their study, Altinpulluk et al. [4] conclude that AR can be used in Cultural Heritage (CH) applications, both in indoor and outdoor, and in different areas, such as, Exhibition, Exploration and Reconstruction of CH. As explained in Figure 2.1.



| Indoor use | Cultural Herritage Applocation | Outdoor use |
|---|---|---|
| **AR** Display: Collaborative, intuitive Interface: HMD, Mobile Devices Tracking: Markerless, Sensor-based | Exhibition | **AR** Display: Collaborative, intuitive Interface: HMD, Mobile Devices Tracking: DGPS, Sensor-based |
| **AR** Display: Collaborative, Multimodal Interface: Mobile Devices, HMD Tracking: Sensor-based | Exploration | **AR** Display: Collaborative, Multimodal Interface: HMD, Mobile Devices Tracking: DGPS, Sensor-based |
| **AR** Display: Multimodal Interface: Mobile Devices, HMD Tracking: Markerless, GPS, Sensor | Reconstruction | **AR** Display: Multimodal Interface: Mobile Devices, HMD Tracking: Markerless, GPS, Sensor |

**Figure 2.1:** Different application areas of AR in CH, and the technical requirements of AR systems in indoor and outdoor settings, according to Bekele M. [1].

Altinpulluk et al. [4] also conclude that most of the AR apps are used in indoor Exhibitions, with mobile devices as display and the most common types of tracking system are:

- Marker-based: Use 2D special visual symbols like images (image target) or QR codes, to track the camera position [1]. It also can use a 3D model of a real object (model target) [4];

- Markerless: Use geometric features in the real environment by detecting and recognizing them, to track the camera position [1];

- Sensor-based: Can be divided in different types of tracking depending of which sensors are being used. Being the most common the Inertial Tracking, that uses Gyroscopes and Accelerometers [1].

From the point of view of the authors, "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". The authors also pointed that besides the AR capabilities, there are still some hurdles that prevent the acceptance of immersive technologies in CH. These hurdles are mainly due to technological limitations, content complexity, and human factors.

Now that we've seen that AR can be used in different ways, and that can be helpful when it comes to improve the learning experience and engaging the user in different areas and places, let's look how museums are using AR.

## 2.2 AR in museums

Museums are learning places, however there are some inherent problems that do not let them reach their full potential. Exhibition space, venues, schedules, inaccessibility and non-interaction with cultural heritage artifacts are some of the problems [5] [6]. Besides that artifacts information is usually passed to visitors by text on information panels or prerecorded audio tours [6]. In this section we analyze different ways of using AR to solve these problems.

First let's look at the ways that major museums are using to integrate that new technology, in their exhibits.

The Art Gallery of Ontario, in Toronto, created an AR application called ReBlink[6] using image target as tracking system, that users could have on their smartphones and when pointed to a painting, would animate that. The National Museum of Singapore is using Google's Tango technology to show the history of the iconic building come alive[7]. Many natural history museums use AR to recreate extinct creatures and prestigious habitats, thus allowing the visitor to learn in an interactive and funny way. Many of the museums use cameras to record the room in real time, and giant screens that pass the image of the room along with a scenario which uses augmented reality. A good example is the Florida Museum of Natural History, which gives life to the mammoth skeleton that is present in the room. Figure 2.2 shows the room of the museum with the display screen.



**Figure 2.2:** Florida Museum of Natural History.

Although these are the ways that some museums are using to enhance the visitor experience. There are many other ways that are being investigated.

Xueai Li et al. [7], developed a serious game based on AR, using Tsingtao Beer Museum as a case study. After studying the museum, the authors found that this museum had the advantage of allowing visitors to observe the objects closely as well as touch them, despite this the visitors cannot describe with a full concept of the production flow after visiting. The fact that the old factory building Tsingtao Beer has been turned into the museum makes that as narrow halls, hampering the movement of visitors, also

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[6]https://youtu.be/mHFzkV20lwQ, Last accessed in 27/12/2019
[7]https://youtu.be/tTJb6-9pvsQ, last accessed in 27/12/2019

the visitors have difficulties to know their position and the progress of the visiting, this may also be since the museum guide is not clear enough. Despite these problems the authors state that they can be solved with AR. The authors developed a mobile application using AR, with model target as tracking system. For the application to be adjustable to all users, they can select each tags that are interesting, to determinate an appropriate game for them. The app will give hints, so the visitors can explore according to their preferences, while exploring the museum, the users can scan the objects, and for each object a mini-game, with a few tasks, appears. If the users complete all the tasks received, they can get some souvenirs coupons. The authors did some user tests and claim that: "visitors can interact with exhibitions joyfully through AR game. Besides, the immersion and experience of visitors will be greatly improved. For the benefits of museums, the application of AR games will increase the sales of souvenirs and attract a number of visitors".

Kyriakou et al. [5], developed a system that combines natural interaction and augmented reality, using model target as tracking system, to solve the problem of inaccessibility and non-interaction with the cultural heritage artifacts. Their user experiences tests, has showed that explore digital 3D replicas of artifacts from the museum, is well accepted by the visitors. Heinz Nixdor museums Forum at Paderborn, in Germany, developed an AR app using a tracking system based on markers. The app is based on user interface, aimed for students, families, and people with professional interests. AR technology for an exhibit has proven to be effective. They also conclude that any hardware used by students should be robustness [8], i.e., the hardware used must have insurance and properly protected for possible falls and hazards. AR-Muse project was developed to see the results of AR in retention and transfer for learning in art museums, the application uses image target as tracking system [9]. Ryffel et al. in [10], developed an AR mobile application using image target as a tracking system, based on simple touch interaction, for museums and art exhibitions. ARtLens [11], an AR app for the Microsoft HoloLens that uses model target as tracking system. The application allows museum visitors to actively interact with and learn about artifacts. From this work we retain the importance of not distracting the visitor from seeing the original artifacts, and that AR is a powerful tool when it comes to engagement and facilitating learning in museums. In a medical specimen museum, was developed a AR system, and it proved that this AR application "enhancing students' motivation for learning" inside the museum. Their study also alerts that, for some people it's inconvenient holding the tablet for a while, and the display need to have a good resolution [12]. A lot of the works presented above need to overlay the AR content to the physical content. To study this, Ohlei et al. [13], created an AR application with image target as tracking system. According to their work it is necessary that the AR content fits into the surrounding space, making it mandatory to be able to translate, rotate and scale the object, so that the object can be adjusted to place it in spatial relation to its environment. They claimed that the best way of doing this is to make the user to select by pressing a button in the lower area of the device, what the user wants to

change (scale, rotation or translation). The users prefer scaling via pinch gestures and the rotation and translation via touch gestures. Yang-chung li et al. [6] discussed the development of digital curation in cultural expression applications. They argues that museums should keep the information about visitors, in order to assess the visitors' behavior, so developers can provide the best solution according to the visitors. The authors also underlined the importance that customization of the application is important to the users. Considering Cooperative AR, Barrett Ens et al. [14] studied how can we improve and create collaborative MR systems. Concluding that, in addition to add value to the MR system, we should create ways where the users can communicate throw gestures and shared visual information. There also should exist mechanisms that, allows to enable awareness of what the other users are doing or need.

Different museums have different problems, and consequently different solutions, but there are problems common to most museums, which are: lack of space, low capability of interact with the exhibitions, poor ability to make the user learn, poor ability to make the user want to know more or return to the museum. During this section, we study the different solutions created, to try to improve these problems. We can conclude that although there is a lack of research on improving the retention and learning in museums, from the researches founded we can conclude that AR has capabilities to enhance the museum experience and help visitors to learn. Also, from user tests already done with Mobile Augmented Reality (MAR) applications, we can extract some results that can help us avoid the same mistakes, like lack of utility of the application in the real world, lack of customization, not using a User Centered Design from the beginning of the developing phase. The main things that upset the users in MAR was its dependability on the internet, lack of previous knowledge about what AR is, lack of flexibility to manipulate the 3D content [15]. Several authors, also described the importance that the technology shouldn't be the reason why people visit the museum, and that the technology shouldn't obscure the interaction between museum and visitors, as well as between visitors with other visitors [7] [6] [11].

## 2.3   Extended Play at Faraday Museum

As explained in Introduction (Chapter 1), this thesis will continue the work done by João Barreto and Luís Nunes. João Barreto [16] [17], 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 happens 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 2.3 shows a image of the Gower-Bell Telephone and Figure 2.4 shows a image of the Gower-Bell Telephone in the AR application.



**Figure 2.3:** Gower-Bell Telephone.



**Figure 2.4:** Gower-Bell Telephone in AR.

The experience of using the application is entirely done in the device, i.e., there is no interaction between the user and artifact. Yet the users found it was interesting and it was possible to see that helped the users to understand the object better. Luís Nunes improved 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 2.5 shows a image of the Dynamo-Engine and Figure 2.6 shows a previsualization in Unity, of the Dynamo-Engine in the AR application.



**Figure 2.5:** Dynamo-Engine.
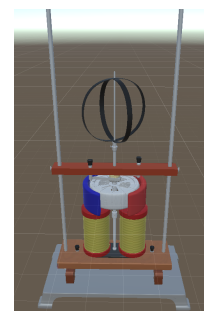


**Figure 2.6:** Dynamo-Engine in AR.

## 2.4  Educational AR

Museum exhibitions tend to explain the objects with a panel beside the object or in prerecorded audio tours. These types of explanations disconnect the link between the object and the visitor, besides that, they are not the best way to educate the user [6]. Since AR can fill the gap of museums that do not offer enough interactive content [6], and according to Wu et al. [4] [18], 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 [4] [18]. So, it is important to understand how, and if we can use AR to educate people.

Abdüsselan and Güntepe 2018 [19] and Moorhouse et al. [20] focused their studies on this subject. The first authors stated that the best way to learn is by trial and error, that students learn much better when they practice and can interact with others, who are learning the same things as well [19]. From the survey elaborated by Moorhouse et al. [20] we can obtain important investigations done in this area that are: Stewart 2014 [21] 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. Lai et al. 2009 [22] also refered the importance of experiential learning. According to their studies [23] [22] digital technologies can help students in learning due to the fact that enables the learning process to be done at any time and place, and in a continuous way. Mobile technologies let you create tools that provide complex tasks and challenging problems to solve. Making them great tools to use in experiential learning [24]. Andre et al. [25], focus their work on how can museums help children learn, and they say that museums that integrate technology and activities in their exhibitions, can positively influence children's' behaviour in discussion and exploration the exhibits, as well influence the critical thinking, create curiosity, excitement and memorable moments. Moorhouse et al. [20] also provides a experimental learning cycle with the following characteristics:

- Learning is a process and not an outcome;

- Learning is a continuous process based on experience;

- To learn is mandatory that the learner understand the whole subject and not in an isolated way;

- learn involves that the learner is uncertain in an environment that can interact;

- learning generates knowledge;

Their study also shows how experiential learning experiences can benefit from integrate AR technology, and evidence that AR can provide immersive and novel museum learning experiences, which was already demonstrated in the previous section 2.2 that users value that.

Morentin et al. in [26] 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. They also said that museums are ideal environments for facilitating children's experiential learning.

## 2.5  User Experience in AR

Although User Experience (UX) is widely accepted in web design, there is still some reluctance to use UX in MAR, Arifin et al. [27] attributes this problem due to the ease of developing AR by non-professionals. The author of this thesis consider that user centered design (UCD) is an important factor for the success of an application. Therefore, in this section we will review the methods used for test MAR applications and services and not the results itself.

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" [28]. UX is fundamentally subjective, it changes according to users and their experiences, as well as the time they experience the product [15]. UX is generally described as an umbrella term for planning, assessing and examining the encounters that user feel while using any item, system or service in a specific setting [29].

UCD is the whole process around developing an application around the users. Starts by understanding who the users are, their needs and problems, and how this application can solve them. It involves a series of application tests with potential users, quizzes, interviews and other methods. UCD is modified through the concept of UX [30] [31].

UX can measure, in a qualitative or quantitative way, different aspects of an application, such as functionality, reliability, usability, efficiency, maintainability, portability and aesthetics [15] [32]. The metrics used to evaluate these aspects, depends on which aspect you want to measure, the type of application and the context. The usability aspect is the most measured aspect of applications [32] [33]. According to Zaid et al. [32], 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. The fact that usability is the most tested aspect of an application, has to do with the fact that it can be divided into different attributes, such as: Efficiency, Satisfaction, Learnability, Memorability, Errors, Effectiveness, Simplicity, Comprehensibility, Performance, Accuracy and User satisfaction/Emotional response [34] [32] [33]. According to Tullis and Albert [35] there are four categories of metrics:

- Performance metrics which are measurements based on user behavior in the tasks given;

- Issue based metric which is a UX measurement based related to the usability issue;

- Self-reported metrics, which are measurements based on user perceptions when interacting with

applications;

- Behavioral and physiological metrics to know the experience felt by the users. This metrics generally requires additional equipment to measure user behavior and emotions.

Dhir and Al-kahtani 2013 [36] used three methods to evaluate UX on MAR prototypes. The first method used is, SUXED which measures the service quality by using user satisfaction level metrics. The second method is AttrakDiff, is a questionnaire and is categorized into three main groups: perceived hedonic quality identification, perceived hedonic quality stimulation and perceived pragmatic quality. That measures the usability level, the level of users' fun and interest in using the application. The third method is Emocard that measures the emotional relationship between the users and the application. Finstad et al. in [37] used Usability Metrics for User Experience, in form of a questionnaire to measure satisfaction, effectiveness and efficiency. User experience in games is evaluated during all the creation process, from concept, pre-development, production to implementation and testing. It used various methods, from questionnaires, interviews, video coding, quantitative comparison of games' behavior, and heuristic evaluation [27]. The tests are done based on a focus group.

To test the AR-Muse application, and see if helped in retention information from Art museums, the authors did a Experiment protocol with three groups. The first group had only the first group visited the museum without the application, the second group visited the museum using the application, the third group visited the museum with the application, but all the text descriptions of paintings were removed. Each group answered a questionnaire with demographic information and AR experience, after that they were able to freely visit the museum. To see which group holds more information, they came back 24 hours later to answer a questionnaire. Olsson et al. [38] [39], used online surveys to mostly gathering qualitative data.

Aesthetics can be measured with Non-Instrumental quality. This attributes measure user needs beyond usability and satisfaction, that is, the look and feel of the application [40]. In this way we can measure captivity, innovation, impression, interest and excitement [15] [40]. Amalfitano et al. [41] presented a framework to automatic testing of mobile applications in Google Android. The framework is based on a crawler that automatically builds a model of the application GUI and obtains test cases, for crash testing and regression testing, that can be automatically executed.

MAR Education applications can be divided into four components: Product, User, System, and Service. Therefore, UX measurement is not limited to products and users, but also includes System and Infrastructure available. Since in general, AR applications involves the use of new technology and equipment [27].

Olsson et al. [39] did an online survey about Mobile Augmented Reality (MAR) applications, with user acceptance. In another study [38] they did an online survey aimed to understand the potential users' expectations of AR and to evaluate specific use scenarios that demonstrate various aspects of

MAR services. From these studies we can conclude that if the application is easy to use and useful, it will be well accepted by users, so it became evident the importance of the applications usability and utilitarianism. We can also notice that even if the application is less useful but funnier to use, the users will also accept it well. These studies can be corroborated by the study accomplished by Dhir and Al-kahtani 2013 [36]. From their study they concluded that users value personalization, novelty, concreteness, reliability, intuitiveness, and the usefulness of given information.

From the research described above, it is possible to note that the most used method to obtain information is surveys, this information can be corroborated. By the survey research done by Altınpulluk et al. in [4], the authors 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 tests 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 [34] [9] [32] [33].

## 2.6   Mobile Application

Dimitrios Raptis [42], made a review of Mobile applications used in museum environments, he suggests that applications should follow the Theoretical Framework of dimensions of context as it was proposed by Dix et al. [43]. In a succinct way, these dimensions are:

- System Context, refers to all the interconnected devices and their applications which constitute the system as a whole;

- Infrastructure Context, describes the way the devices and their integrated applications are connected;

- Domain Context, is related with the adaptability that every system must provide to the specific characteristics of different users;

- Physical Context, is related to the nature substance of the device and the system as a whole.

The author describes the importance of understanding the relationship that exists between the exhibition and the visitors, and based on this, choosing technology that best fits the intended purpose.

According to Henry Tsain [44], museums are at the forefront of adopting mobile technology to enhance visitors' experience. From his point of view, is important to allow a customized visit, for that he suggest four ways:

- customized tours;

- wayfinding, i.e., getting oriented inside the museum and navigating from place to place;

- bookmarking;

- social media technology, allow a integration between the museum app and the social media apps.

In addition to that, there are several ways to enhance the interaction and learning:

- Multimedia tour, an attempt to replace prerecorded audio tours;

- Augmented reality, according to the author, "The ability to overlay content atop reality creates exciting possibilities for education and entertainment in the museum environment";

- Casual Games, it is not only a good way to attract visitors but also to pass on knowledge.

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.

In developing MAR for education, it is necessary to consider three approaches [45] [18]:

- User approach, if it is to be used by a single user or by a group. Will it allow communication between different smartphones?

- Location approach, where users are going to use the application;

- Task approach, how to design learning tasks in MAR.

From the researches presented above, we can reinforce our opinion on how AR can improve the experience of visiting a museum. We can also withdraw how to structure our application and some additional features that our application may have.


## 2.7 Relate Work Discussion

From our Related Work we can retain several important points that support our app, and several points to take in mind when developing the game.

From Sections 2.1 we can notice that AR is being used in different areas with different objectives but it is always well received from the users. According to Altinpulluk et al. [4], AR mobile app can be used to exhibitions and exploration in indoor, thus a validation of the basis of our work.

In Section 2.2 there are several examples of AR apps in museums, that we can take as guide of good work. We can also take important knowledge to consider when developing the app, like the importance to have space for the user to move around the object, and user customization. Thus extracting important information to consider while developing the application, avoiding problems later on.

From Section 2.3 we can understand how the app was being developed until now. We can retain the importance of explaining and guide the user by giving objectives, explanations and hints.

From Section 2.4 we can retain important information as AR can be used to learn and educate users. We would like to point out the phrase: "Learning is a continuous process based on experience" by Moorhouse et al. [20]. This phrase is important since, it's where we based the user progress in our app.

From Section 2.5 we can understand better what UX is all about, the importance of a UCD perspective and retain several examples of how others are doing it. We can notice that most developers use surveys to gather the user opinion, and the majority of them use the User Experience Questionnaire. We also can stress out that usability is the most measured aspect of app, and that UX should be measured in all phases of the development.

From Section 2.6 we can take important features that the app should have, and important approaches to consider before develop the app, like User, Location and Task approach. These approaches help us plan how our app will work and connect to the museum.

# 3

# Development Context Analysis

**Contents**

As mentioned in the Related Work (Chapter 2), museums are a place with potential for learning, due to the fact that museum curators have knowledge to share and usually the artifacts or replicas are learning sources.

So, to solve this problem we decided to continue the development of the AR Android app "Extended Play at Faraday Museum" which aims to improve the experience of the museum visitors.

Since the application already had two objects, we chose another one with the help of the museum curators. The object chosen was the Cathode Ray. In the next section (Section 3.1) we present brief description of the Cathode Ray.

## 3.1 Cathode Ray

Cathode Ray is an object that makes possible to focus and control an electron beam (e-bean) by changing the electric and magnetic field. To be able to see the electron beam is necessary that the experience occurs in a dark room.

Since the object was designed to be used in experiments, it is full interactive, however is quite hard to understand how to interact and to understand what is happening it is necessary to have knowledge in the electromagnetism field.

Succinctly, by changing the intensity of the coils, the tension of the e-bean and the rotation of the ampule, the e-bean takes different shapes, with different sizes and thickness. Being possible to make different variations of lines, circles and spirals.

In figure 3.1 is possible to see the object with two coils, that generate a magnetic field, and in Figure 3.2 is possible to see the object in a dark room, and the e-bean (in light blue).[1]



**Figure 3.1:** Cathode Ray object, with two coils.



**Figure 3.2:** Cathode Ray in a dark room. The e-bean with a circle shape.

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[1]The pictures was taken with the iPhone 11 Pro, that has a especial mode to take pictures in dark environments.

## 3.2 Analysis of previous work

To understand why we chose this object, it is important to understand the work already done from my colleagues. So, you can see the differences between our works.

The object augmented by João Barreto et al. [17] was the Gower-Bell telephone, the object augmented by Luis Nunes is the Dynamo-Engine, that is still in progress. A brief analyses of their work are presented in the following Subsections (Subsection 3.2.1 and Subsection 3.2.2).

### 3.2.1 Gower-Bell Telephone analysis

From the object, and the application we can retain several important points:

- Visitors cannot touch the object;

- The object doesn't change during the AR experience, i.e., there is no interaction between the user and the object or by the mobile phone and the object;

- The experience is all done on the mobile phone;

- It is a iconic object of the museum, since it is an old IST phone;

- The application helps the users to understand how the telephone works, in a more interactive way compared to reading a sign;

- The work as a focus group from 12 years upwards, which understands Portuguese. For this reason, the app is written in Portuguese in a more child-friendly way;

- The app contains two scenes: one with a book, that works as an initial menu, and one with the Gower-Bell augmentation.

- The project repository has a lot of unused assets, scripts and scenes, that harm the efficiency and efficacy of the project.

The game consists of fixing the Gower-Bell telephone. The users need to drag and drop some of the Gower-Bell telephone objects and click on them to make them work. All the UI elements have the same background, an image imitating an old paper sheet, Figure 3.3.

An overview of this app can be visualized in Figure 3.4.

### 3.2.2 Dynamo-Engine analysis

The object animated by Luís was Dynamo-Engine, and since is developing at the same time as us, we weren't able to analyse in detail his work.

However, from the work that we have access, can retain several important points:
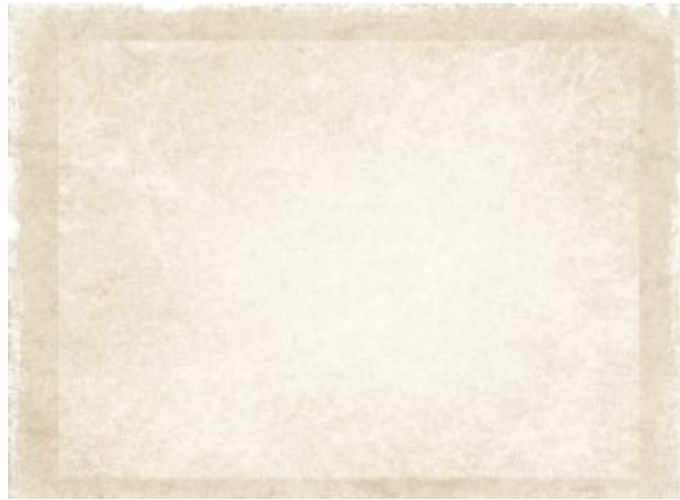
**Figure 3.3:** Old paper sheet- background image.



**Figure 3.4:** Gower-Bell Telephone app overview.

- Visitors can interact with parts of the object in "real life", that affects the rotation of the engine;

- The parts of the object that the users can interact is not the part that the users can use the augmented reality app;

- The user only interacts with the object, and uses the app to understand what is happening;

- The application helps the visitors understand some electrical and magnetic concepts;

- Improved the system of objectives created by João et al. [17].

The book created by João et al. [17] conveys an idea that the app will tell a story about the museum and its objects. It also conveys an idea of the interconnection between old technologies (books) and new technologies (mobile phones). In our way of seeing, the idea of being a book is very well achieved, and fits very well in the context of the application. However, from the tests realized by Luís, it is possible to see that the users spent to much time in the book, having a hard time to understand how they start

the mini-game, this is due to the fact, that there is no "Play Game Button", there is a clickable image, but there is no visual/text effect saying that. So, Luís work contains the work done from João et al. [17] on the same scene, i.e., both games are on the same scene, this occurs, since according to him, the app should start in the scan mode, without passing by the book. So, in his work, there is no book and when the users start the app they are already "filming" the museum and there is a button to select with which museum artifact they want to interact.

## 3.3 Solution details

### 3.3.1 Design Aspects

After analysing the application, and the above mentioned points, we decide to chose an object that the visitors had a hard time understanding, and that we felt that some type of interactive learning environment would improve the learning experience of the visitors. We also wanted to have an object that the visitors could fully touch, since this was, so far a restriction with the chosen objects and that the AR app would be about the same part that the visitors are interacting. And that's why, we chosen the Cathode Ray.

The Cathode Ray, also allows us testing how AR behaves in dark rooms, and how users feel while using a mobile App with AR in dark rooms. However, this seems more a limitation than an advantage, it's something we want to investigate.

To bring even further this investigation, we decided with the museum curators, that interact with the application, would also change the object. That is, it will be possible to change the intensity, tension and rotation, not only on the object but also in the AR app.

From the investigation done for this thesis presented in the Section 2.4 we can see that a experiential learning experience can improve the motivation and retention of the students. So, we aimed our application in this type of learning experience. For that we let the user try different things, allowing the user to commit mistakes without penalized them, but giving them hints to understand what is wrong, and learn from all this experience. With this in mind, we designed and developed our application, this process is described in Chapters 5 and 7.

To improve the app, we also cleaned the repository and improved some coding mechanics to help the future developers, as described in Section 7.2.

We also created a Technical Report[2], were we analyse the work already done and we document our work. This document should serve as a reference for future programmers, as it contains technical decisions and explanations of the code. It also contains a Wiki&How section to guide programmers on

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[2]https://github.com/ruiprada/FaradayMuseumAR/blob/Android/Project/Documentation/Technical%20Report.pdf, Last accessed in 17/12/2020

some essential things in app development.

## 3.3.2 Technical Aspects

The application was migrated and developed in Unity 2018.4.18f1 Long Term Support version and Vuforia 8.3.8 version. For now, the application will not be available in any app store, and it's just deployed in the museum tablets (Samsung S5-e tablet with 2560x1600 screen resolution). However we created a responsive UI design, so it can later be deployed for everyone.

The application doesn't allow communication between different mobile devices, is designed to be used by a single visitor, or a group of visitors as a single user or as a local co-op by one user that interacts with the application and the other user interacts with the object (user approach) and is designed to be used in the Faraday Museum (location approach).

We use model target as a tracking system. The Bluetooth device and the engine that rotates the ampule are going to be developed by the museum curators and they will also add bobbins and change the wooden base color of the Cathode ray object so that it allows a better experience.

In terms of the application context:

- System context: The only devices that are interconnected, are the smartphone and the Bluetooth. But the smartphone is tracking the real object by using the camera to know its position relative to the object;

- Infrastructure context: Since we are using the camera' device to track the object, the necessary user interaction with the object to complete the objectives can't make the user obstruct the object visualization by the camera;

- Domain context: The user is going to be able to personalize the application in terms of his knowledge of the thematic taught in the Faraday Museum;

- Physical context: To interact well with the application is necessary some free space that allows the user to face the object and that the user can move away or closer to the object.

In the Figure 3.5, is a flowchart of our application. In the Figure 3.6, is a basic interaction system of our application.

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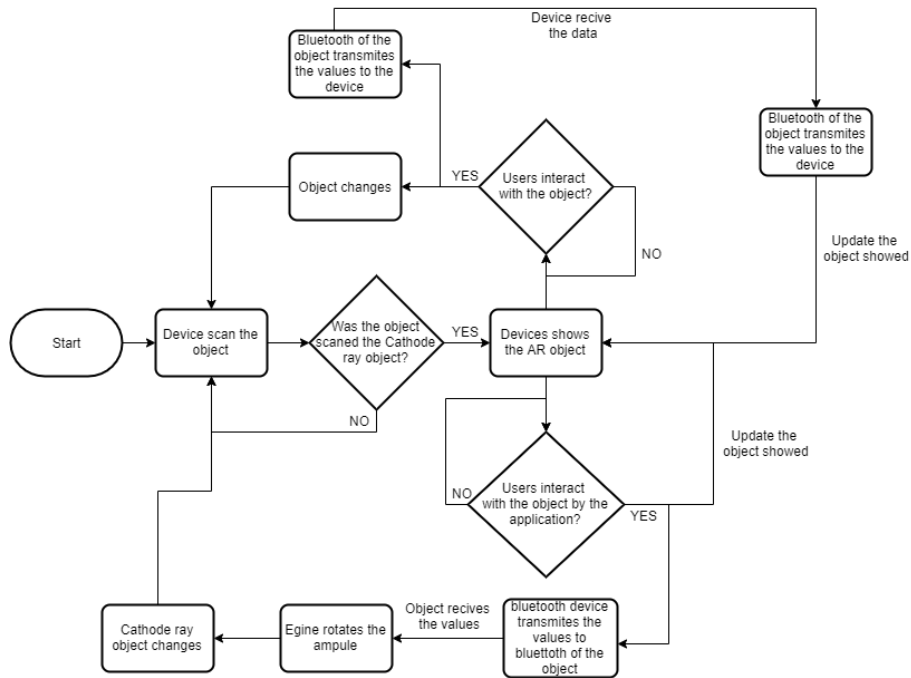
**Figure 3.5:** Flowchart of our application.
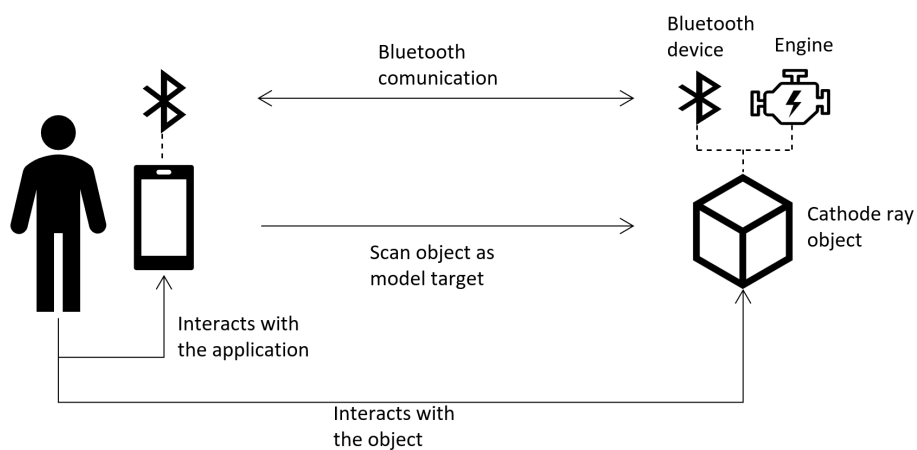


**Figure 3.6:** Basic interaction system of our application.

**4**

# Faraday Museum Dissemination

**Contents**

During the development of this thesis, we participated in different Faraday Museum dissemination's, to show our work. Not only to get feedback, but also to show to another museum's curators, or people interested in the area, that AR is a possibility to improve the visiting experience in their museums.

## 4.1   Second meeting of the heritage of the University of Lisbon

The first dissemination that we participated in was the second meeting of the heritage of the University of Lisbon, held at the Faculty of Fine Arts, with the Faraday museum directors. Professor Carlos Ferreira Fernandes, one of the Faraday museum directors, presented the work done by them at the museum, and introduced the work already done in the context of this thesis. We showed the AR application developed by João Barreto et al. [17] and improved by Luís Nunes that animates the Gower-bell telephone, were meeting participants could test the application. In total we had 4 people testing the application and many to see them testing, all of them said it was a great initiative, and one stressed the importance of these mechanisms to capture the interest and teach the younger ones.

Although these tests do not follow as user test methodology, being that, it was not the goal to test the application but to make it known. However, it was important, because all the users, had a special interest in Cultural Heritage. Almost all of the participants had an important role as curators in one of the Museums of the University of Lisbon Faculties. And since all the feedback received was very positive, served as a kind of approval for the upcoming work.

## 4.2   Faraday Museum guided tours

In February of 2020, the Faraday Museum received about 600 high school students, from the area of science and technology, from different schools. Due to the high number of visitors in such a short time, we were asked to help with the guided tour. Therefore, we had the opportunity to interact with the visitors and see how they behave in the museum. We also understood how the guided tours work on this particular museum.

We had also the opportunity to show the work done by João et al. [17]. The application was received with great enthusiasm by the students.

Still about the use of the application we could notice that the visitors showed a lot of interest, curiosity and motivation to learn more, some even showed discontent because there were no more artifacts with this type of interaction.

We also made the guided tour of our object, the Cathode Ray, where the students showed great fascination, however, some had difficulty understanding and visualizing the magnetic field.

It was also noticeable that visitors prefer interactable objects, regardless of the form of interaction, be

it visual, touch, or sound. In other words, objects that stimulate at least one of the senses of the visitors. They also showed great attention when learning something related to the subject given at school. Like seeing real examples of the Newton laws.

# 5

# WebGL App

## Contents

It was our idea to start the Android app development as soon as possible. However, due to the pandemic that was happening and the imposed lockdown we had some challenges with the future of our application than needed to be solved before having the App ready. These challenges are described in the next section 5.1.

## 5.1   Challenges raised by COVID-19

Unfortunately, this thesis had some constraints due to COVID-19. At the start, we had the idea of beginning as soon as possible the development of the Android app, doing small development phases, accompanied by user tests, so we could improve our work while we do it. However, this was not possible due to the quarantine time implemented. Since it was not easy to ask someone to test our application remotely, note that it was necessary, that the user install the app, and print the image target, to be able to start the test.

So we decided to first develop an Web Graphics Library (WebGL) app instead of an Android AR app, with the objective of being able to share and test, so we could test and improve our interface.

WebGL is a JavaScript API for rendering interactive 2D and 3D graphics, and is compatible with every web browser without the use of plug-ins. WebGL allows GPU-accelerated usage of physics and image processing and effects as part of the web page canvas. And above all, allows us to mix the WebGL content with HTML elements. This means, that we can put our work, on any web site.

Due to COVID-19, it was also hard to find an artist, since we weren't able to show them the museum and the object, explain them the context. Or take pictures, measures and necessary notes. Without that was hard for an artist to modulate or to create an interface that fits in the museum.

Until we were able to share our WebGL version to the users, to solve the missing user experience problem, we did small showcases, as a quick demos of the work implemented. That were recorded and sent to people and ask them their opinion, in order to get most feedback possible in our app.

Since the museum don't have any focus group, anyone can be a good candidate for user tests. However, it is important to gather information from different user groups. With WebGL version, we are able to date, since we can spread the link through the Internet. This development phase is explained in the following section (Section 5.2).

## 5.2   WebGL App

In this section we are going to explain the work we had done to create our WebGL App. However, the final product of this thesis is an Android App, so during the development of the WebGL app, we had to have into consideration that this is an Augmented Reality app, and all the advantages and disadvantages, that

may bring to our app.

Our idea is that 10 years from now, this project will still work and the student who picks up this thesis will be able to understand and change what is necessary without holding too much time, or messing with too much code.

So, during the development of the app, we tried to have a long term methodology, so we designed and programmed thinking this way. The decisions made on how we programmed and designed the code, was always thinking, to facilitate the understanding of the project to the next person who takes the project.

The first thing, to have our app working, is to understand and create the psychics that we need in Unity. This process is explained in Subsection 5.2.1.

### 5.2.1 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. So, we used the formulas calculated by Professor Carlos Fernandes.

There are three values that we are going to receive from the Cathode Ray or our control panel, that are: intensity, tension and the rotation.

With intensity (I) we calculate the magnetic field (B)

$$B = \mu_0 * (\frac{4}{5})^{\frac{1}{5}} * \frac{n * I}{r}$$

Where $\mu 0$ is the magnetic vacuum permeability and have the value $\mu_0 = 4\pi * 10^{-7}$, r is the radius of the coils and have the value $r = 155mm$, n is the number of turns in the coil and have the value $n = 130mm$

With the tension (Ua), we calculate the initial velocity (v0)

$$v_0 = \sqrt{2 * \frac{q}{m} * Ua}$$

Where q is the electron charge $q = 1,6 * 10^{-19}C$ and m is the electron mass $m = 9,11 * 10^{-31}Kg$

After this we are ready to calculate the desired shape.

So, our Cathode Ray can make 3 shapes: a line, a circumference and a spiral. The first thing we need to know is what shape to draw. So by the rotation of the ampule we can know this.

If $\alpha = 0, 2\pi$, straight trajectory, the movement is uniform with speed $v_0$ according to positive x axis.

$$x(t) = v_0 * t, \quad (x(t) > 0) \text{ and } y(t) = z(t) = 0$$

If $\alpha = \pi$, straight trajectory, the movement is uniform with speed $v_0$ according to negative x axis.

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$$x(t) = -v_0 * t, \quad (x(t) < 0) \text{ and } y(t) = z(t) = 0$$

If $\alpha = \frac{\pi}{2}$, the trajectory is circular with radius R, described with an uniform movement ($v_0$ constant accounts) in the zy plane.

$$\begin{cases} x(t) = 0 \\ y(t) = R(1 - cos(wt)) \\ z(t) = R(sen(wt)) \end{cases}$$

With radius:

$$R = \frac{v_0 * m}{q * B}$$

If $\alpha! = 0, 2\pi, \pi, \frac{\pi}{2}$, the trajectory is a spiral with radius R

$$\begin{cases} x(t) = v_0 * t * cos(\alpha) \\ y(t) = R * sen(\alpha) * (1 - cos(wt)) \\ z(t) = R * sen(\alpha) * sen(wt) \end{cases}$$

With radius:

$$R = \frac{v_0 * m}{q * B}$$

After this we were ready to draw the e-bean.

### 5.2.2   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 research 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 better control of what we are drawing.

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

However the interpolation, has a problem, when the radius is too small and the number of points is too high, the points get to close, and instead of a circle we get different shapes depending on the ratio number of points / radius. Since there is no given relation between this, we did several tests, for our

possible radius, and we found out that for a radius smaller than 0.05 cm we need to reduce the number of points. We reduced the number of points to 40, since this works for our smallest radius possible and steel looks like a perfect circle. For a radius bigger than 0.05 we use 1000 points, so we get the most flexible circle possible.

To modulate the e-bean we created a blue material and draw use it in the Line Render, 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.

The following figures (Figure 5.1, Figure 5.2, Figure 5.3), are the result of the work done so far. In Figure 5.3, is possible to see the spiral with fade blue e-bean, representing the part that is not visible in real life.
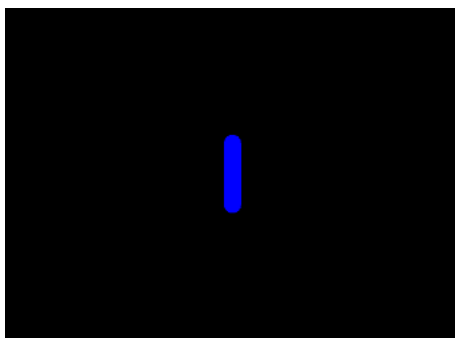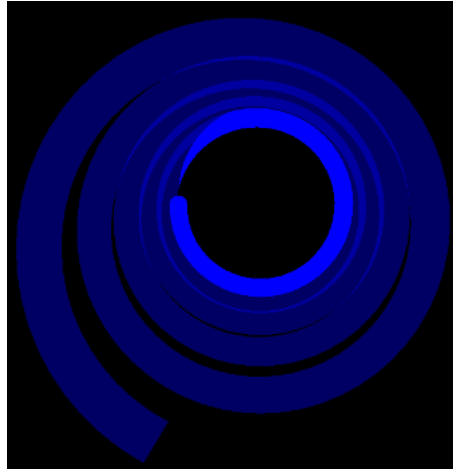


**Figure 5.1:** Line, Intensity = 1.5 A, Rotation = 0º, Tension = 100 V.
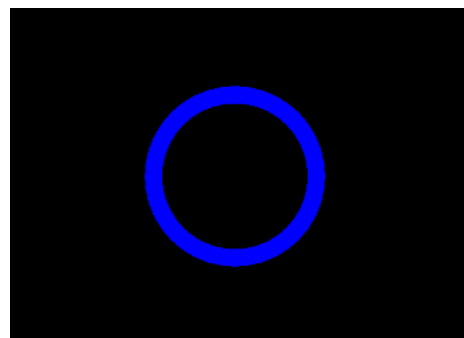


**Figure 5.2:** Circumference, Intensity = 1.5 A, Rotation = 90º, Tension = 100 V.

To create this fade line, we had to implement a shader. Because, in AR the position where we starting 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

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**Figure 5.3:** Spiral, Intensity = 1.5 A, Rotation = 100º, Tension = 100 V.

model, it will not be affected.

To a deep understanding, the Listing 5.1 contains the Shader code. From line 2 to 6 are the parameters passed to the shader. In line 9, is possible to see that we inform the render that this is a transparent element, that makes that this is rendered after every other element in our scene. And that in line 12 we disable the Z buffer. This is mandatory, so that the fade blue line shows what is behind her. In the vert function, line 37 to 46, we convert the coordinates of the point, to a world position. In the frag function, lines 48 to 53, we calculate the color, of the point we're currently drawing by calculating his distance to the center of the ampule, and see if is bigger than the ampule radius.

**Listing 5.1:** Color by position Shader.

```
1   Shader "Unlit/ColorByRadius" {
2       Properties{
3           _DefaultColor("Default Color", Color) = (0, 0, 1, 1)
4           _AugmentedColor("Alternative Color", Color) = (0, 0, 1, 0.392)
5           _AmpulePos("Ampule World Position", Vector) = (0, 0, 0)
6           _Radius("Radius", float) = 0.09
7       }
8       SubShader{
9           Tags{ "Queue" = "Transparent" "RenderType" = "Transparent"}
10          // Alow transparency
11          ZWrite off
12          Blend SrcAlpha OneMinusSrcAlpha
13          Pass{
14              CGPROGRAM
```

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```
15          #pragma vertex vert
16          #pragma fragment frag
17          #include "UnityCG.cginc"
18
19          uniform float4 _DefaultColor, _AugmentedColor, _AmpulePos;
20          uniform float  _Radius;
21
22          struct vertexInput {
23              float4 vertex : POSITION;
24          };
25
26          struct vertexOutput {
27              float4 pos : SV_POSITION;
28              float4 worldPos : TEXCOORD0;
29          };
30
31          vertexOutput vert(vertexInput input) {
32              vertexOutput output;
33              float4x4 modelMatrix = unity_ObjectToWorld;
34              //Convert the point to World Coordinates
35              output.pos = UnityObjectToClipPos(input.vertex);
36              output.worldPos = mul(modelMatrix, input.vertex);
37              return output;
38          }
39
40          float4 frag(vertexOutput input) : COLOR{
41              //calculates the color of the point
42              float4 color = _DefaultColor;
43              if (distance(input.worldPos, _AmpulePos) > _Radius)
44                  color = _AugmentedColor;
45              return float4 (color);
46          }
47          ENDCG
48      }
49  }
50 }
```

However, this shader has a problem in the case of the circumference there are always to 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 second 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.

The next step was to create a UI, so we could change the values of intensity, tension and rotation.

### 5.2.3  The User Interface

Since WebGL runs in the browser, the app needs to target different resolutions and we can take advantage of screen size. We also need to have into consideration, that the users will mostly interact by mouse / keyboard.

The first step, was to look at the work already done, and check the type of UI elements used, the font color and size of the text and titles used, and the images / backgrounds used. The second step, was to analyse how they used this UI and for what reasons. So, we could recreate a similar UI to make the app consistent, that would work for us.

We could notice, that they used objectives, and hints to guide the user, and explanations to give information to the user, when he completed an objective. And all of this appeared as pop-ups.

Concerning the elements used, they only used buttons, and the pop-ups already referred. All of the UI elements had the same background, like an old paper sheet. The text was written in black, with Arial as font, for the titles it had Font-size 50 and for the normal text 40.

The third step, was to decide how should it be our UI. We decided that we need three types of elements to change the values, buttons (increment and decrement), slide and text input.

The text input, allows a quick change of the value to a specif value, very useful when the user knows exactly what value he wants.

The slide, allow a quick change between value, with low interaction cost, useful, when the user wants to have a quick perception of what those values change in our application. However, it's hard to go to a specif value.

The buttons, allows to change the value in a more controlled way than the slide, that is, it is possible to reach a specific value, however it requires more time and interaction than text input. This element is particularly used, when the user does not know the exact value but has some idea of the value he wants to try.

In Figure 5.4, is possible to see our simple UI, that would allow the user to change the values of the ampule in the app. This group of UI elements, is referred to throughout this thesis as the control pane.

At that moment, we decided to use four decimal places for each value, since we wanted to have an extremely accurate and real application. The buttons would increment or decrement one value. We created a warning, Figure 5.5, that is triggered every time a user try to insert a unacceptable value. For example: a value smaller than the minimum value for the respective field.

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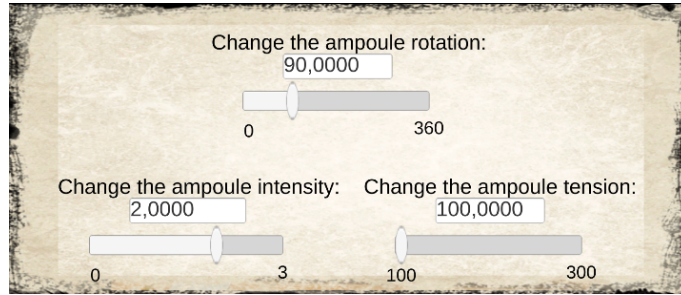
**Figure 5.4:** Control Panel- tablet version.



**Figure 5.5:** Warning- User tried to insert a value smaller than the minimum value.

We also had to create our own buttons, Figure 5.6, for that we used the Adobe Photoshop. Please, take in consideration, that we are not very skilled with this tool.

The following list contains the buttons designations and their behavior:

- Control panel button: enable and disable the control panel;

- Hide / Show objects: enable or disable all the object expect the ampoule and the e-bean, allowing a better view of the e-bean;

- Hide / Show the AR: enable or disable the augmentation of reality done in the project, for example, the fade blue line. Allowing to see exactly what you see on the museum;

- Object rotation: Allow to rotate the object in the three axis, allowing to see the object from every point of view. Note that this is not the ampoule rotation, but the entire Cathode Ray rotation;

- Reset object rotation: Reset the rotation, given in the point above.

At this time, only the first button was working, that disable and enable the control panel. The other buttons would be necessary for a later part of the project, see Subsection 5.2.4.
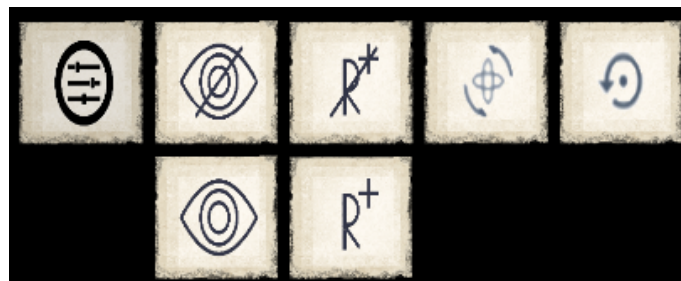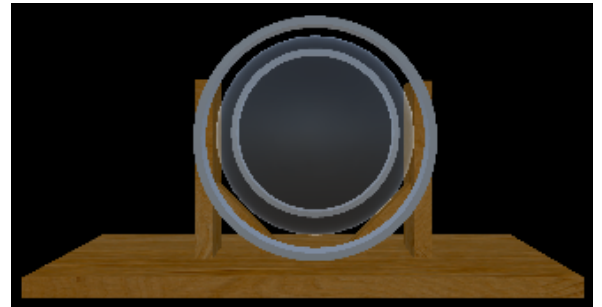


**Figure 5.6:** First version of our buttons.

To have the application as close to reality as possible, before we put all these elements together, we modulate a 3D version of the Cathode Ray. Since we still did not have the work from the artist, we

modulate ourselves using Blender, however, as we are not experts, we kept the object as simple as possible without much detail. We did two versions, as it is possible to see, in Figure 5.7 and Figure 5.8. The first one, had some wrong proportions. We keep the details simple, but add textures to the coils and wood. We used Unity to generate and add a normal map, which created much more detail and more realism.
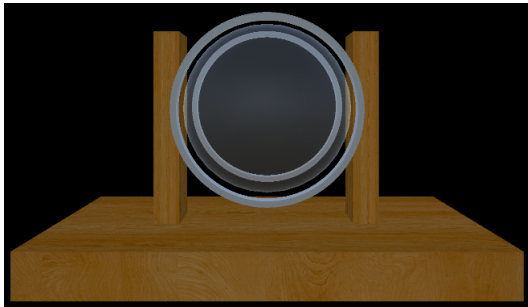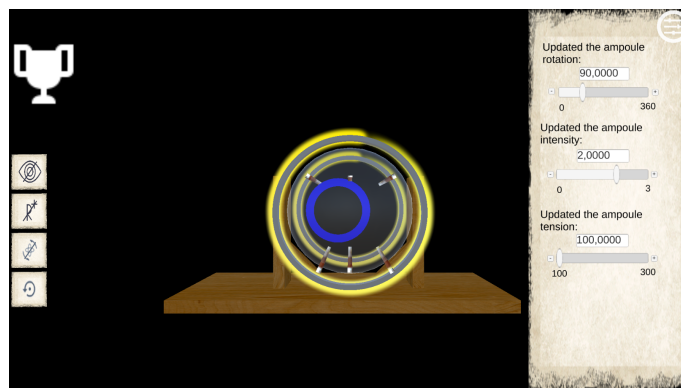


**Figure 5.7:** First version of our Cathode Ray 3D model.



**Figure 5.8:** Second 3D model of the Cathode Ray 3D model.

To put all of this together, as a good practice we first draw a paper sketch of our UI, and then we implemented in Unity (Figure 5.9).



**Figure 5.9:** First Version of our WebGL App.

Note that the Reset object rotation button don't appear, since this only appear if the Cathode Ray already has been rotated. In the left top corner is possible to see a white button, that makes part of Luis' work. This button allows to change between objects.

In relation to the pop-ups, as referred to in Subsection 5.2.3, there are four pop-up categories: Initial Pop-up, explanations, hints and game end pop-up.

The only difference with the work of my colleagues, is that they aimed their app to a mobile resolution, since we are on WebGL. We decided, that to take advantage of the size of the screens, making bigger pop-ups, that would benefit elderly visitors. We add a little bit of transparency to the background, so the user could see the application behind, and in this way, improve the look & feel of our app.

An example of a pop-up can be visualized in Figure 5.10. The descriptions used in the pop-ups, were made with the help of the museum curators.
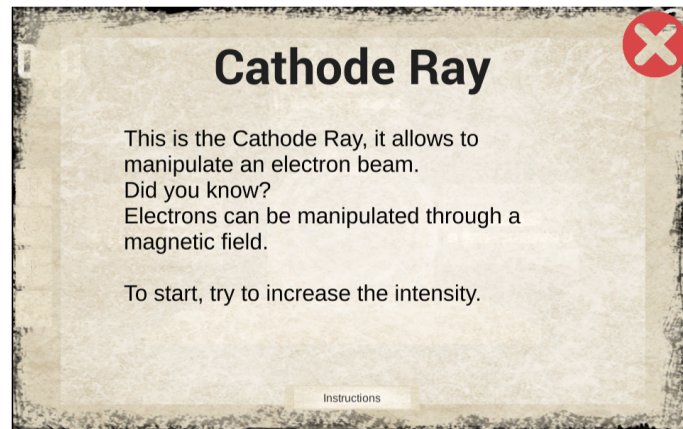


**Figure 5.10:** Initial Explanation in WebGL.

We implemented a logic to see the pop-ups already visualized, by pressing the "Pop-Up Button" (Figure 5.11), it appears the first pop-up visualized, the initial explanation pop-up, with a left and right arrow. The users can use the arrow to change through the pop-ups already visualized, if there is only one pop-up, the arrows are disabled and presented with a grey color, the standard value for a disable UI element. This can be visualized in Figure 5.12.
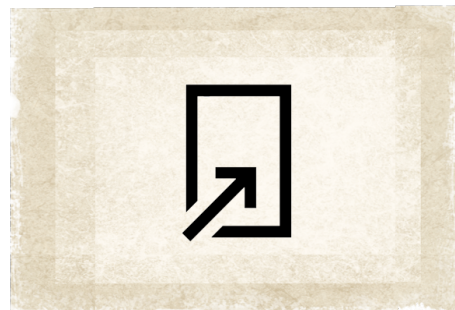


**Figure 5.11:** Pop-up button.

For the Hints, we follow the same logic used in some mobile games, such as Candy Crush[1], that is, after a while without accomplishing any objective the game highlights one way of completing one objective. In our case, it is not easy to highlight the path to accomplish the objectives, since there may have to be many interactions to complete an objective. So, instead of highlight, we make a pop-up appear on the screen, describing what the user needs to do, to complete the objective. As it is possible to see in Figure 5.13.

We implemented instructions (Figure 5.14), that consists of an image of the application with text explaining each UI Element. For consistency reasons, when clicking to see the instructions, this image

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[1] https://play.google.com/store/apps/details?id=com.king.candycrushsaga&hl=pt_PT, Last accessed in 31/07/2020
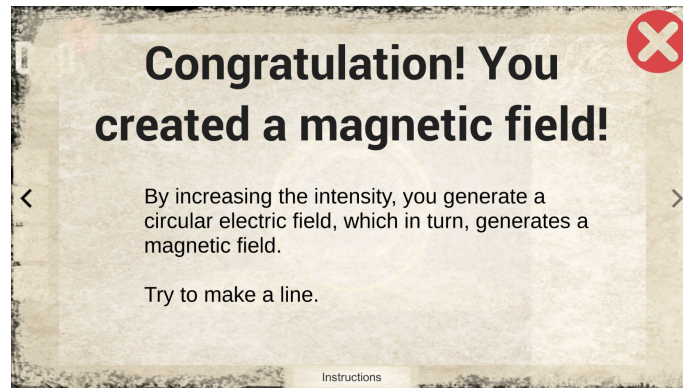
**Figure 5.12:** Pop-ups slider.
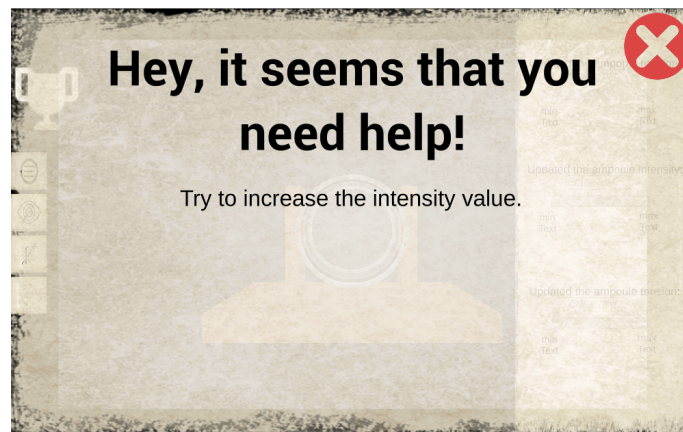


**Figure 5.13:** First version of our hints.

also has the old paper sheet as background (Figure 5.15). For the button we decided to use an old paper sheet background with a text saying Instructions, since we thought that it would be the best option.

After a few play-tests done by ourselves, and a better analysis of our work, we decided to change the interface again. Since we did not have any more the initial book we didn't have to continue using the old paper as background, and since the app did not need to be consistent, because only our work was passed to WebGL, we could create an interface of our own.

The control panel as it was, in the right side, add the advantage of having everything on the same place, however since we had more things on the same place, it was hard to read and not taking advantage of the other places of the screen. For example between the buttons and the Cathode Ray Object. It was also hard to know what we were changing, since there was no visual connection between the UI elements and the 3D model.

So, we decided to change the control panel in tree, this is, create one separated "box" for each propriety, and add a connection between it and the 3D model, to allow a quick understatement of what this propriety changes in the Cathode Ray. For the background we use a grey background with a few
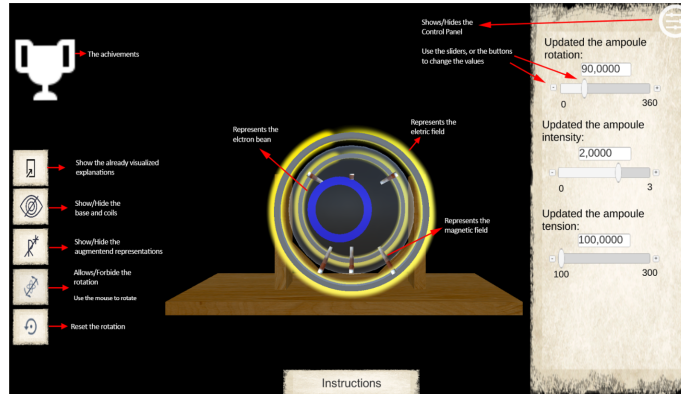
39

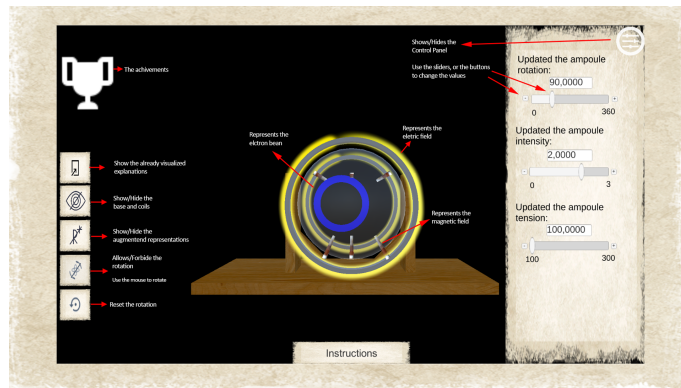**Figure 5.14:** First version of the instruction.



**Figure 5.15:** Second Version of our WebGL App.

transparency. That allows us to read well everything and see what is behind. This is important because of the 3D rotation of the object.

Since we were not sure about which was the best connector for the Tension box and the e-bean, we did two options. We also changed the instructions according to this new UI.

All of these changes are possible to see in Figure 5.16 and Figure 5.17.

In Figure 5.16, is possible to see a connector between the Tension box and the e-bean that goes over the entire model. In Figure 5.17, is possible to see a darker connector that goes behind the coil and trough the wooden. They have different colors, since we also wanted to see what was the best color.

In the Figures is also possible to see a pink horizontal arrow, this was a feature added to our 3D model, that indicates the ampule rotation. That is better visualized in Figure 5.18

### 5.2.4 App Improvements

Since the idea is to turn this into an augmented application, we need to augment the reality. To improve the experience of the user, we decided to augment the electric and magnetic fields. Not only to allow the users to see something, they can't see in real life, but also so the user can see what interactions change

40
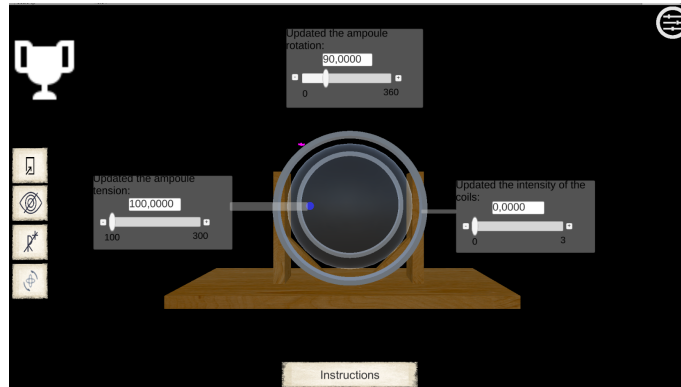
**Figure 5.16:** Second Version of our WebGL App.
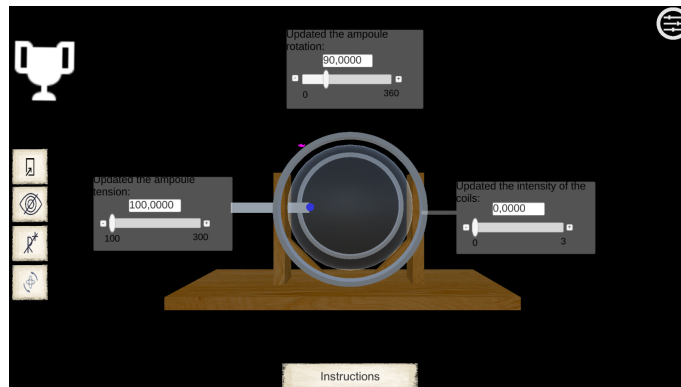


**Figure 5.17:** Third Version of our WebGL App.

these fields and how. Creating in this way, a learning experience.

For the electric field, we ask people how they imagine the electricity, and if they had to draw it, how they would do it. The most common answer was: like a line or a group of lines with color yellow/orange. There were a few people that describe the electricity as circles, because of the electrons.

Since the electric current, has a way, and that in our case is circular, we decided to implement a circumference using the particle system. We decided to use a particle system, because is a real efficient manner, to create visual effects. We can manipulate the electric field in a very fast way, without needing as much processing as if we were using 3D objects, also is very efficient when it comes to creating and destroying particles.

To indicate the direction of the electric field, instead of a static color we use a gradient from transparent - yellow - dark yellow. This gradient is passed through the particles, that is, the first particles go from invisible to darker, while the last ones disappear. We also create particles with a smaller size, which increases until reaching the maximum size, giving the idea of a trail. In Figure 5.19 is possible to see the electric field and in Figure 5.20 is possible to see the electric field around the coil. Unfortunately, it is not possible to see in the Figures, but the electric field, is constantly rotating. Passing the idea of
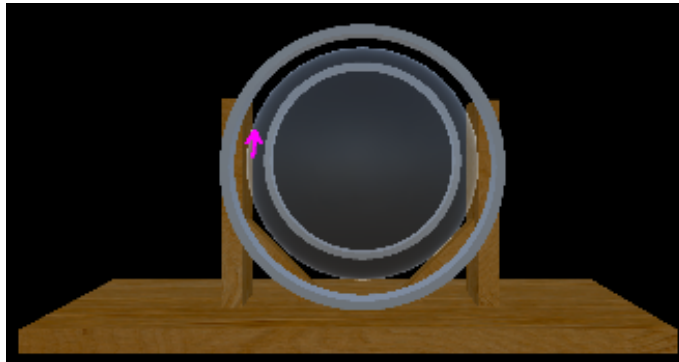
**Figure 5.18:** Third Version of our 3D model- pink arrow added.

movement, and thus indicating the direction of the field.

To indicate the strength of the electric field, that changes according to the intensity of the coils, we change the size of the particles. Creating a smaller or bigger circumference.
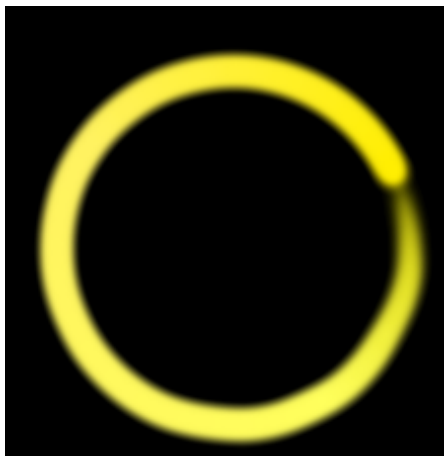


**Figure 5.19:** Representation of the electric field.
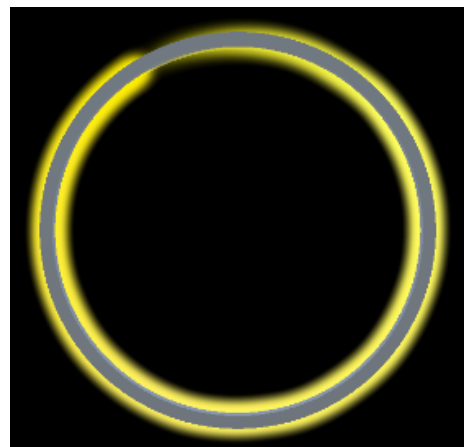


**Figure 5.20:** Representation of the electric field around the coil.

For the magnetic field, we used the augmented representation created by Luis, that is possible to see in Figure 5.21. We are not sure, that this is the best representation to our case, but we strongly support consistency within the app, and having different ways of representing the magnetic field, would break this strongly. However, we showed people this representation and although people didn't think it was obvious, they said it made sense.

This representation is made by creating a line, using the Line Render Component, and constantly changing the offset of the texture material. That is half white, half brown. In this way, is possible to indicate the direction of the magnetic field.

Since, with this representation we could indicate the direction of the magnetic field, and the strength by changing the speed that the offset changes, we believe that the users will understand this represen-

tation. Also, this is made with the Line Render Component, which is very efficient, and that is one of our criteria, to decide what we use. Since, it is for running on a mobile phone, which may not have large processing capacity.
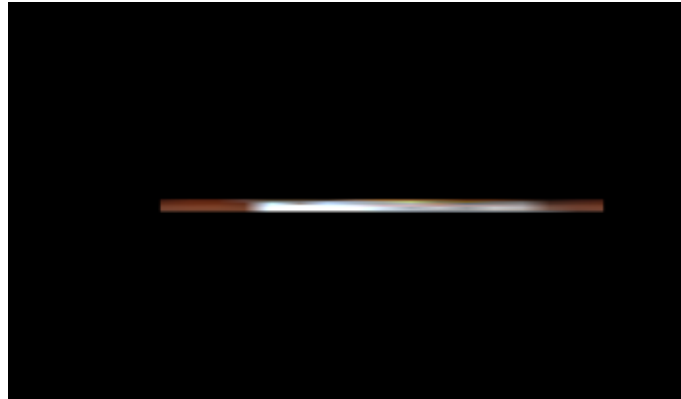


**Figure 5.21:** Representation of the magnetic field.

To update the size of the particles and the speed of the offset according to the intensity, we create a function, Listing 5.2, that converts the intensity value, to a value between two values, that we discovered by hand. This conversion, can't be made by the Rule of three since the scales are not proportional to each other. For example the intensity changes from 0,1 to 3 Amperes and the size changes from 0,7 to 1,7 Unity units.

When the intensity is 0 the electric field and the magnetic field are disable.

**Listing 5.2:** Number converter of the intensity value to the size of the particles.

```
1  private float NumberConvert(float i)
2  {
3      float size = (((i - minI) * (maxR - minR)) / (maxI - minI)) + minR;
4      return size;
5  }
```

With this implemented, we started working on the 3D object Rotation. From our Related Work, Chapter 2, we can see that this is important for the user. The fact that he has the free will to see the object from the point of view he wants, and also helps the user to center the object if necessary. In Section 2.2, due to the work done by Ohlei et al. [13], we could see that users prefer to rotate objects by touch gestures. The author implements a rotation system, that allows rotating the object by each axis, by rotating the axis. However, the rotation implemented has Gimbal lock.

Gimbal lock, according to Wikipedia [46], is defined as "the loss of one degree of freedom in a three-dimensional, three-gimbal mechanism that occurs when the axes of two of the three gimbals are driven

into a parallel configuration, "locking" the system into rotation in a degenerate two-dimensional space".

We strongly defend, that a system with Gimbal Lock is a loss of free will and that harms the user's experience. However, the author, proved that the users would rather have the axes there. So, we implemented a rotation with the 3 axis visible to the user but without Gimbal Lock. This system was inspired in how game engines and 3D computer graphics software allow the user to rotate 3D objects, like Unity and Blender.

With this done, we implemented the buttons shown in the Figure 5.6. As said in the Subsection 5.2.3, it was missing the implementation of the buttons: Hide / Show objects, Hide / Show the AR, Object rotation and Reset object rotation. Due to missing assets, that now are implemented.

In Figure 5.22, is possible to see the default view of our application, this is, with the object in front-view, with the electric and magnetic field represented. In Figure 5.23 is possible to see the result of pressing the button Hide/Show objects. In Figure 5.24 is possible to see the result of pressing the button Hide/Show AR. In Figure 5.25 is possible to see an example of a possible rotation of the object, this rotation allows us to see the magnetic field, electric field and the e-bean from another angle. If after this, the user presses the reset rotation button, the object returns to his default position, which is possible to see in Figure 5.22.
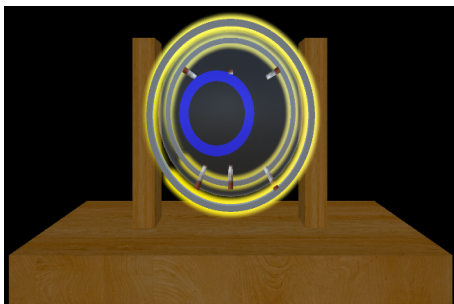


**Figure 5.22:** With the extra objects enable (default value).
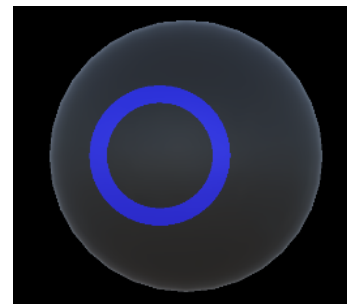


**Figure 5.23:** After pressing the button to hide the extra objects.
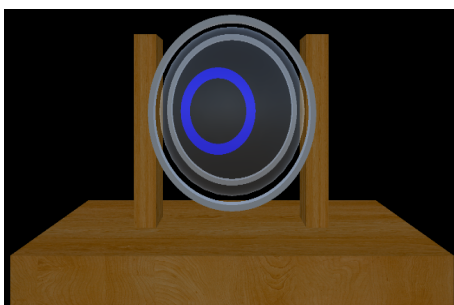


**Figure 5.24:** After pressing the button to hide the AR.
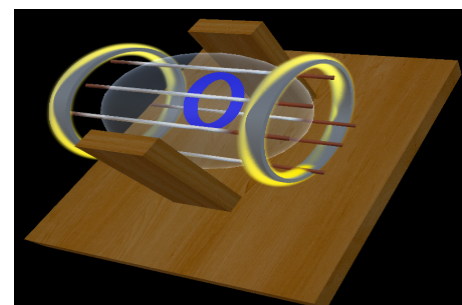


**Figure 5.25:** One example of a possible 3D rotation.

To juice the game we implemented few animations, when the pop-ups open and closes. The anima-

tion implemented is a simple fade-in / fade-out transition. We chose this animation, because we don't want to make a fancy game in terms of visual effects, but some simple, good looking and practicable interface. And that is what fade-in / fade-out is all about.

For the animations duration, the basic rule of thumb, is that animations should take between half a second to a second. We decided to use 0.40 second, since this looked to us as the best duration for our case. We implemented this animation to all the pop-ups and changed the other animations existing on the app to this duration.

### 5.2.5 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.

Unity, provides Unity Analitics [2]. That, is a way to get information about how users are using the application. We can customize the information collected according to our desire. It has the main advantage that the information is directly passed to charts, that allows us to quickly interpret the data. However, the information takes at least 8 hours to be updated, i.e., there is a gap of at least 8 hours with reality. The feature, that allows to download the data, is only available in Unity Pro, which has a too high monetary cost for us. So, we are stuck with the charts and relations given by Unity. It has yet the requirement that the device needs to be connectes to the internet, so it can send the data.

Unity, gives an alternative to send info to a web server, UnityWebRequest [3]. With this alternative we need to implement the logic to send the data and to keep the data on the server. We also need a web server. However, this is more time consumption, we have more control and we can combine this logic with saving a file on the phone for backup. So we decided to implement this alternative.

For that, we use the IST web server, which is located on our personal page. This server it's public access, and this may be a problem due to the new data protection laws, depending on data saved, that's why this should be used only for interaction data, no personal info is kept. However, the biggest problem, is the web server is the developer personal web server, so every time the developer changes, the server needs to change, and this may cause a loss of data. Besides that, if there are two or more developers at the same time, there will be two places recording different data of the same project, or shared passwords, so we intend to pass this to the museum personal page.

We kept the information recorded in a object for storage space reason, and in time to time we send the information to the server. The information in the server is stored as txt file and in the android system as JSON File. The serialization necessary to this, it was implemented by us due to library's conflicts with WebGL and Android.

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[2] https://unity3d.com/pt/unity/features/analytics, Last accessed 19/05/2020
[3] https://docs.unity3d.com/ScriptReference/Networking.UnityWebRequest.html, Last accessed in 01/08/2020

Since with WebGL, is possible to have multiple users using the application at the same time, by having several users accessing our application at the same time, or one user with multiple tabs open in our app. We need to ensure that the name of the Log file is unique for every entry in the app. For that we created a system, that gives the file name, according to the date of creation (Year-Month-Day_Hour-Minute), and by 14 random digits, with this we create a unique ID[4]. This system has a really low probability of having two equals IDs generated. Being that, 2020-05-14_12-24_1703666_1535180.txt is an example of a file name, given by this system.

Another option was to ask the users to add a nickname and add this to the file name, that would give even a less probability of having the same ID generated. However, there are some users that use common nicknames or their name. Since, the log tests recorded are stored on our personal website and this is not safe and is publicly accessible, we can't ensure the privacy of the information. For this reason we don't store anything personal, or that allows to identify the users.

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[4]https://en.wikipedia.org/wiki/Universally_unique_identifier, Last accessed in 01/08/2020
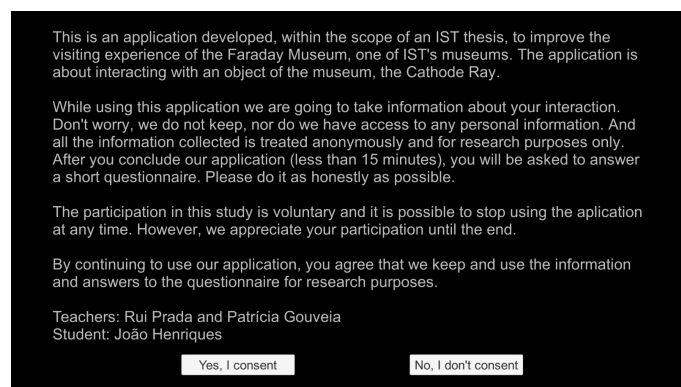
# 6

# WebGL Evaluation

## Contents

To create an user centred app, that is well received and easily used by every user, we tried to make several user tests during the development phase, as explained in Chapter 5. In this Chapter, we are going to detail the two most important user tests that we did regarding the WebGL app.

## 6.1 Pilot Tests

To test our app, we had to change a few things.

Since, we are going to store information from the user, we need to ask to our users if they agree to participate in our study. To make that, we decided to create the consent form in our app. Since it is more user friendly, doesn't need more separators and links, and since we don't need to store any information about the user, we don't need to keep a formal record of a acceptance by the user. This consent was made according to the Guide to Informed Consent by IST[1] and can be visualized in Figure 6.1.



**Figure 6.1:** Consent Scene.

If the user press the No, I don't consent button, they are redirected to google webpage. If they consent, they see the instruction with a play button. After pressing on the play button, the game starts.

For the users tests, described in Section 6.2, we needed to had a questionnaire, and for this reason we needed to connect the app to the questionnaire.

So, in the end, we created a pop-up thanking the user and asking to answer a questionnaire. If the user presses the button, it will open the google form, with the log file name placeholder automatically field.

To make this we had to create a pre-field questionnaire, and fill the log file name placeholder with the tag |*FILE_NAME*|.

After generating the pre-field questionnaire we get a link for this questionnaire, in our case: `https://docs.google.com/forms/d/e/1FAIpQLSdZq6hoDsuPIF5vdX1ceHgA2nduqopJGreP97TT2GgTjH3mug/viewform?`

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[1] `http://etica.tecnico.ulisboa.pt/`, Last accessed in 03/09/2020

`usp=pp_url&entry.596911872=|*FILE_NAME*|`. What this link says is, that in our questionnaire, the answer with the ID 596911872 has the value |*FILE_NAME*|, and automatically fill in with that value. So, in our application, instead of passing the |*File_NAME*|, we pass the actual log file name.

By having the questionnaire connected to the log file saved in the server, we intend to be able to understand some answers to the questionnaires, by having a better visualization of what the user did in our app.

We decided to give only access to those who finished the application, as they would have a better opinion about it.

After this, we build everything and tested. We launched it to our IST personal web site[2] and started to plan our test. This test is described in the next Chapter, Section 6.2.

However, before we start testing we wanted to make sure that we had the best version possible, this is, without bugs and glitches. We also wanted to make sure, that users understand our app, and we had thought about all the possible use cases. To ensure that, we decide to make pilot tests. With this, we also could test the test itself, i.e., see how users handle the test, the time spending in each phase and what they think about our questionnaire. The test in a brief way has the following structure: the users start using the application, and after complete each objective a pop-up asks the user to answer a questionnaire. If the user presses the button, it redirects the user to the questionnaire link.

### 6.1.1 Pilot Tests Procedure

For the pilot tests, we selected 5 friends that could helped the most, by different characteristics, like English skills, interface design skills, quality assurance skills, game design skills.

After contacting each friend we agreed an hour and asked them to join us in Zoom, after joining, each user shared their screen, so we could exactly see what they were doing. The test they made, is the same test that would be launched, that is, the use of the application and answer the questionnaire.

The pilot tests went so well and gave us so much feedback, that we decided to do it again, to gather more feedback, and evaluate the changes done with the feedback received previously.

The results of these pilot tests are described in Subsection 6.1.2.

### 6.1.2 Pilot Tests Results

From the first series of pilot tests we gather the following feedback:

- On average users take 15 minutes to use the app and 10 minutes to answer the questionnaire;

- The pop-ups appeared so fast when an achievement was completed that it was impossible to understand what was happening;

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[2] `http://web.tecnico.ulisboa.pt/~ist181633/FaradayMuseum/CathodeRay/`, Last accessed in 05/11/2020

- The users preferred the second version of the connector (Figure 5.17) but with the color of the first version (Figure 5.9);

- The achievement button is not well received by being different from the others, and users don't press it first;

- The instructions button is also not well received.

- The tension and rotation do not need to have four decimal places, they can be integer values;

- When clicking to visualize the pop-ups already seen, show the last pop-up instead of the first;

- Users seem lost on what is the next step;

- Minor bugs, like text with different size, hint timer didn't reset.

All the feedback above was extremely important to the improvement of our app, and these improvements can be visualized in Figure 6.2.
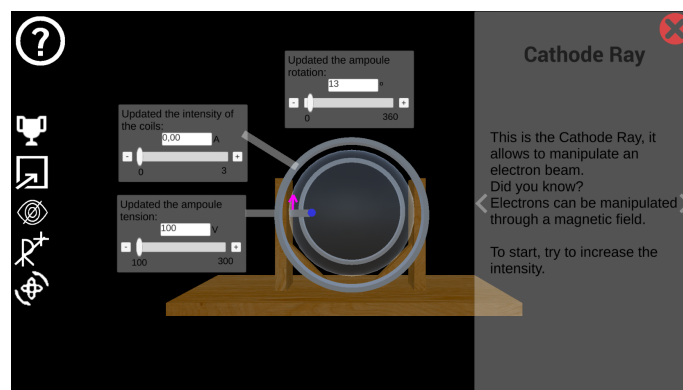


**Figure 6.2:** Fourth Version of WebGL app.

However, we can highlight the second point: "The pop ups appeared so fast when an achievement was completed that it was impossible to understand what was happening". We were so used to the app, that for us it was obvious what was happening, but it was easy to see that the remaining users, didn't understand what was happening. Since whenever they completed an achievement, a pop-up appeared that covered the object. And when the users closed it, they were already concerned with completing the next one, and not understanding this achievement.

This led us, to reorganize the UI, so that we have space on the right side, where the pop-ups now appear, not blocking the object's view. So the user can read the explanation and compare it with what he sees in the object. We also, implemented the logic to see the last pop-up instead of the first one. However since we had this logic implemented, we decided to start with the arrows already enabled, i.e., it was possible to change between pop-ups if there was more than one pop-up already visualized - without need to click the pop-up button.

We also change the instructions button to a question mark button, and decreased the size of the achievement button to match the others, and removed the animation.

Since, our app was the only app in WebGL, and we didn't use the book in this version, it doesn't make sense to continuing to use the old paper sheet background. So, we converted the buttons to white with a transparent background, creating a good contrast with our black background and giving a better look & feel.

We changed the Tension and the Rotation to integer values. We change the Intensity to allow two decimal places, since it has a small scale, and the e-bean is very influenced by it. However, we decrease the increase and decrease button to 0.2, instead of 1, in the intensity case.

We changed the instruction to fit this new look, and since the game is being to play on a computer, we wanted the players to play on full screen. So, we add a big arrow pointing to the full screen button indicating that the users should press there. Note that we couldn't put the game in full screen by our self, since it runs in a browser and for security reasons, apps can't put in full screen by themselves. For this reason, the button to play in full screen is not part of our game, but part of the web page. In Figure 6.3, is possible to see the instructions on our web page.
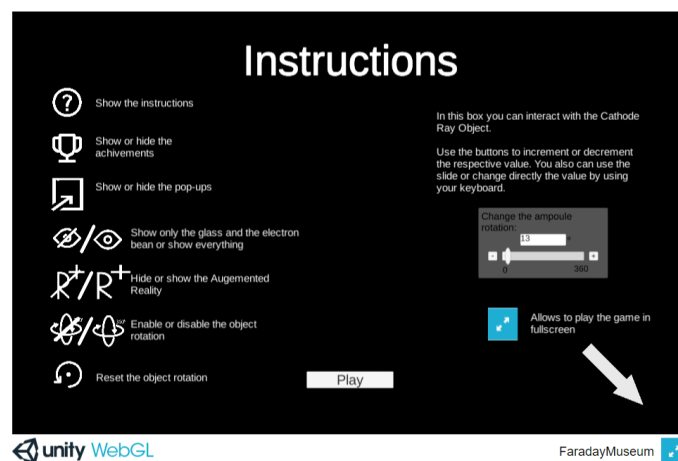


**Figure 6.3:** Second version of Instructions viewed in our web page.

During the tests it was possible to see, that the users were lost in what to do next, so we decided to change the way the game is organized. Until now, the user had to make all the tree shapes possible: line; circle; and spiral. Being that they had to make two circles, one smaller and one bigger than the ampule. However, they could complete these objectives by the way they want.

From the tests done, we noticed that, the users were not benefiting from this. So, we tried a new way. We implemented the game as if it was a tutorial, after all, the idea of this game is to learn how to use and understand a Cathode Ray. So, we decided that the objectives need to be completed in a order:

- Line;

- Circle smaller than the ampule;

- Circle bigger than the ampule;

- First Spiral;

- Second Spiral;

The circles done could be any circle, if the entire circle fits in the ampule. For the spiral, since there are a lot of option, we decided to choose two specific spirals that are very different between them and that makes the user to use all the app.

We also had tooltips to the buttons, indicating what the button does, when the user put the mouse over the button. We made several versions, ending up choosing the one that can be seen in the figure 6.4.



**Figure 6.4:** WebGL app tooltips.

After fixing the bugs encountered, we did the second pilot tests. Where we gather the following feedback:

- The changes were very well accepted;

- Align consent margin with the instructions margins;

- Align pop-up margins;

- Not every user understands that he/she should play the game in full screen.

- Remake the design of the buttons;

- Remake the instructions to ask the users to play the game in full screen;

- Remake some texts, to better understanding;

- Resize the hint to the middle, with a less transparent background.

Since not every user understands that he/she should play the game on full screen, we decided to ask it, in a more obvious way. Creating this panel, Figure 6.5, that appears after the users accept the consent, and before the instructions.

Since we changed this, we also changed the instruction to not contain anymore the arrow to click on the full screen button. The result is showed in Figure 6.6.
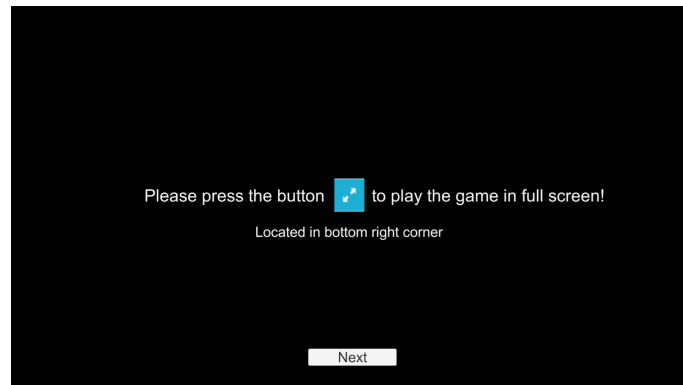
**Figure 6.5:** Full screen panel.
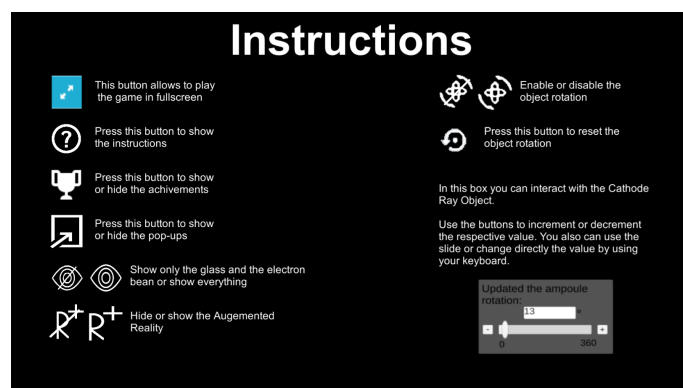


**Figure 6.6:** Third version of the Instructions.

For the hints, the users didn't like that they occupy the same space as the other pop-ups since when the hint appears the other pop-ups are closed. Forcing the user to close the hints and open the pop-ups, to see them again. So we decided to make the hints appear in the middle of the screen above everything else, with a slightly different background. This technique is used, in several games: Forest Home[3]; The Lego Movie[4]. It is possible to see an example of a hint in Figure 6.7

After changing the rest of the points above mentioned, we had our final version, Figure 6.8, and we were ready to start testing.

Just to resume, the order of our application is:

1. Consent (Figure 6.1);

2. Full Screen (Figure 6.5);

3. Instructions (Figure 6.6);

4. Game (Figure 6.8).

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[3] http://thebinarymill.com/forest_home.php, Last accessed in 04/08/2020
[4] https://store.steampowered.com/app/267530/The_LEGO_Movie__Videogame/, Last accessed in 04/08/2020
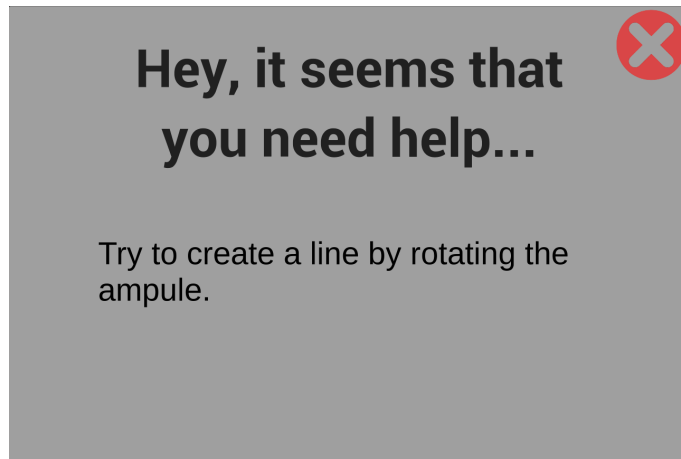
**Figure 6.7:** Second version of our hints.
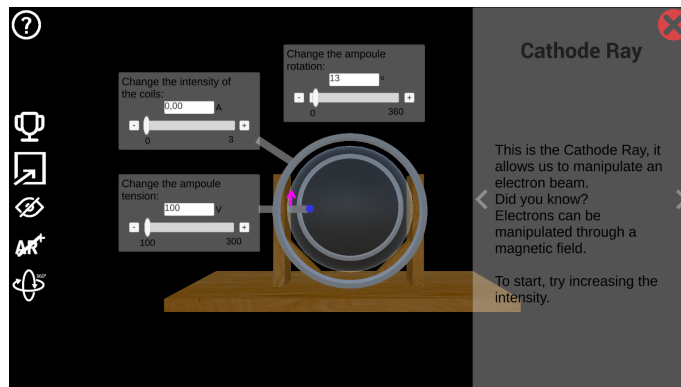


**Figure 6.8:** Fifth Version of WebGL app.

After these we did the main WebGL Tests, described in the following Section (Section 6.2.

## 6.2 WebGL Online Tests

Since the application was changed to WebGL, it turned quite easy to share the work, and ask for feedback. With this in mind, we put our app online, available here[5].

To help planning the test, we wrote a test guide, present in the Appendix A.

This test had the goal of evaluating our application, in terms of interface design, ease of use, efficiency, stimulation and understanding, and the Augmentations of the electric and magnetic field.

Since the museum receives visitors from every age, and with different academic qualifications, there isn't a focus group, so anyone can be a potential user of our app. So, the requirements to tests our app are:

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[5]http://web.ist.utl.pt/~ist181633/FaradayMuseum/CathodeRay/, Last accessed in 15/09/2020

- A computer connected to the internet;

- Browser that allows to run WebGL;

- Knowledge of English.

To contact these potential users and spread our test, we posted a short text, explaining the concept of the app and asking if people could play and answer the questionnaire. The text was posted in several Facebook Groups (Game Development groups, and IST groups), we also posted in several subreddits. We also contacted by direct message some friends.

As said in Section 5.2, we connected the app to a questionnaire that had several questions that allow us to evaluate what the users think of our app. The questionnaire had the goal to evaluate the interface, it was done in google forms and it was divided into five sections:

- 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 had questions to evaluate our interface, and to understand what the users perceive about our application.

- the fifth section thanked users and allowed them to leave extra feedback if they felt it was necessary

In the third section we decided to use the UEQ, since this is one of the most used and best quoted questionnaires to evaluate user experience. This questionnaire measures the attractiveness and classical usability aspects (efficiency, perspicuity, dependability) and user experience aspects (originality, stimulation). UEQ also offers a set of tools to help analyse the data. This tools helps by calculating some important statistics for UX like the confidence intervals, KPI Calculation, answer distributions, inconsistencies in the answer and sample size. The tools also generate several graphs to easily understand and share in articles/presentations. The UEQ also gives a tool to compare UX study between two versions of the same application, allowing us to quickly compare the answer from this study to a study from a future version.

Also according to UEQ Handbook [47], the UEQ is short enough to be applied online. However, in online studies it's possible to have a higher percentage of persons who do not fill out the questions seriously. According to the handbook, a simple strategy to filter out suspicious responses is to change the order of the items that measure the same aspect, i.e., not always have the negative aspects on the same side of the scale and the positive side on the other side.

According to them, a good metric to use is changing the order on the scale between points of the same scale, i.e., sometimes the positive point is at the right sometimes it is at the left. In this way, if a user answer always the highest value of the scale or the lowest, means that he didn't answered the questionnaire seriously, so we can remove him from the research. Another good thing about UEQ tools, is that they have already this metric implemented, making our job easier.

To complete these questions we ask them what was the best and worst part of using our application.

The full questionnaire is present in Appendix B.

To evaluate our augmentations of the electric and magnetic field, we decided to ask the users what they think about them, by showing four images and ask them what is the image that best represents the electric and the same for the magnetic field. After that, we ask them if they think this is a good representation. If they answer no, we ask them what they would change.

To perceive if the users understand what is our application about and the concepts behind the app. We ask them if they can describe what changing the Rotation, Intensity and Tension does, and we give them several sentences, and we ask them to select the ones that best reflect what this application is about, in their opinion.

With this, we don't want to evaluate if the user gained any knowledge, since is very hard to measure this, and for that, we would need to measure the knowledge before the user uses our application. Instead, we want to validate our interface, by understanding if the users, after a play through our app, can identify what changing the interface does in our app.

In the end, we thank the users for their participation, and we let a place, where they can give any extra feedback that they want.

The results of this text, are presented in the following Subsection 6.2.1

## 6.2.1 WebGL Evaluation Results

We had the test open during August, and we had 203 entry's in our game, note that not all of these entry's represents people wanting to participate in the study, some of them are ours from checking bugs and server issues, and some of them may be miss clicks. From this entry's we collected 35 answers, this is, 35 users completed the game and answered the questionnaire.

From the log files of the ones that didn't answered the questionnaire (178 users), 24 of them didn't wait for the game to load, and 25 gave up on instructions. We assume that this together is the users that miss-click in our link (27,5%). 10 users (5.6%), finished the game, but didn't answer the questionnaire. From the users that did at least one achievement, 28 users (15.7%) only did the first achievement, which is the easiest, and gave up immediately afterward, without even giving time to appear the hint for the next achievement (1 min). 48 users (26.9%) were unable to make the third achievement. Only 13 of them had tried enough to receive the hint, of which 5 gave up as soon as hint appeared. From the 8

users that tried to complete the achievement without success for enough time to see the hint and tried to solve it after reading the hint, they still did not succeed. This can indicate that the hint is not useful enough. The rest of the users (24.3%), did at three or four achievements.

From this data, is possible to notice, that the majority of the users give up in the second or third achievement, which may mean that the learning curve is harder in this area. It also shows that the majority of the users, gave up as soon the game gets harder, not wasting significant time trying to solve the achievement, which may mean that these users were not interested in the game. Meaning that, even if the game were easier, does not mean that these users do not eventually give up.

From the log files of the users that finished the game, it is possible to see, that most users use the "slide bar" to change the values, and sometimes completes achievements by chance. By using the slide bar and passing by the respective value. It is also possible to notice that, few users didn't understand that it was possible to change directly the value on the "input text". Being that two things in our UI, that we need to improve, however, these problems are not an impediment to the user finishing the game.

It is also possible to see, that a lot of users used the hints to complete some achievements, some of them completed the achievement right after closing the hint. Showing this way, it helps users to advance in the game, and to prevent them from getting stuck in an achievement.

Although, the 8 users that read the hint and yet didn't completed the achievement are in the minority, this technique is an important part of the game, which facilitates the gameplay, deserving then being revised. Since the biggest problem happened in the same hint, it may mean that the problem is not in the mechanics of the hints, but in what this hint said, it may not be explicit enough.

From the 35 users that answered the questionnaire, 68,6% of our users were Male, 22,9% Female and 8,6% preferred not to say. Every user had between 14 to 60 years old, being the most common, 71,4%, between 19 to 25 years old, and the second most common, 20%, between 26 to 40 years old. 5.7% users had between 14 to 18 years old, and 2,9% between 41 to 60 years old. In terms of academic qualifications 40% had a Masters degree, 37,1% Bachelor's degree, 11,4% $12^{th}$ grade, and 5,7% Ph.D. and $9^{th}$ grade.

From the UEQ section in our questionnaire, we can obtain the following results. Concerning to each point, all the results were good. Being that the most important points for us, according to the objective of this thesis, are: enjoyable, understandable, valuable, supportive, good, easy, efficient, friendly. Where we had extremely good results.

The UEQ questionnaire rates the app in 6 scales (Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, Novelty). The first 5 scales are rated as good, and the last one is rated as average, as it is possible to see in Figure 6.9. This result is justified by the fact that this game without AR is nothing new. Although we do not know games that treat the same, the controls, objectives and purpose of the game are common.
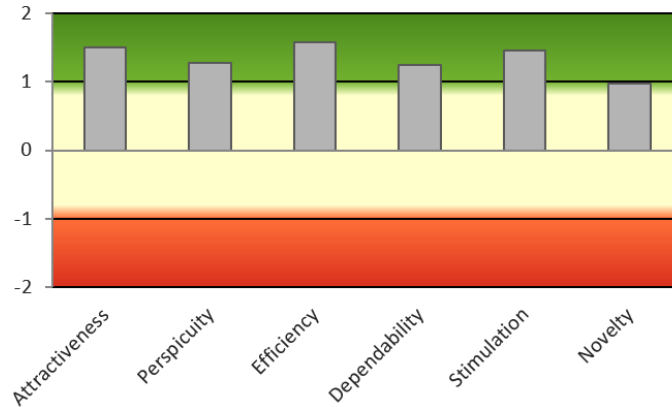
**Figure 6.9:** The UEQ results relative to the scales Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, Novelty. (Red- bad, Yellow- Average, Green- Good).

The scales of the UEQ can be grouped into pragmatic quality (Perspicuity, Efficiency, Dependability) and hedonic quality (Stimulation, Originality). Pragmatic quality describes task related quality aspects, hedonic quality the non-task related quality aspects. The results of this grouping, can be seen in Figure 6.10. In this chart is possible to see that all scales are in a good area. This two charts together can show us, that most rated quality's in our app, is about what the look and feel of our application, this is, what the user does and see in our app. Being that the goal of this tests is to test the interface and usability of the application, are very good results.
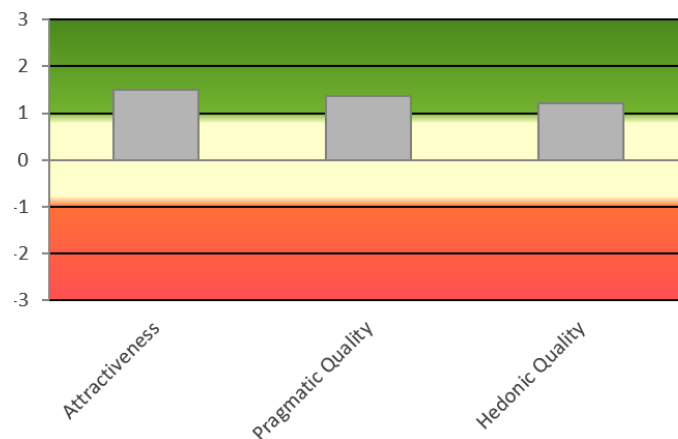


**Figure 6.10:** The UEQ results relative to Attractiveness, pragmatic quality and hedonic quality.

In table 6.1 is possible to see the 5% confidence intervals for each scale. The confidence interval is a measure for the precision of the estimation of the scale mean, i.e., the smaller the confidence interval is, the higher is the precision of the estimation and the more you can trust your results.

The width of the confidence interval (last two columns) depends on the number of available data and on how consistently the persons judged the evaluated product. The more consistent their opinion is the smaller is the confidence interval.

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Is possible to notice, that, in the column "Confidence", the values are very small, meaning that, our results are very trustful.

**Table 6.1:** Confidence intervals (p=0.05) per scale.

| Scale | Mean | Std. Dev. | Confidence | Confidence interval | |
|---|---|---|---|---|---|
| Attractiveness | 1,510 | 1,140 | 0,378 | 1,132 | 1,887 |
| Perspicuity | 1,271 | 1,213 | 0,402 | 0,869 | 1,673 |
| Efficiency | 1,586 | 1,101 | 0,365 | 1,221 | 1,951 |
| Dependability | 1,250 | 1,016 | 0,337 | 0,913 | 1,587 |
| Stimulation | 1,464 | 1,195 | 0,396 | 1,069 | 1,860 |
| Novelty | 0,971 | 1,241 | 0,411 | 0,560 | 1,383 |

Concerning the rest of the questionnaire, when asked the users, what was the worst part of using our application, the majority of the users that answered, the answer was related to the learning curve, saying that at first, it was really hard to know what was supposed to do. A few of them said that over time, it became easier. In the words of one of the users: "The first glance made me confused, but it explained well and it was good". The second most common answers was about the lack of scientific knowledge on the part of users.

When asked about what was the best part, the majority of the answers, was related to the power of this app as an educational tool, the second most common answer, was related to the ease and clarity of the app. A few users, also highlighted the fact that the game had several explanations, hints and objectives that guide them throw the game.

These results are very positive. From the most common answer, we can cite the following answers: "It felt like a good educational tool for school", "It is fun to learn how something works through a game or and interaction rather than just read about it". These answers are very positive, since they support the objectives of this app.

When asked to select the picture that better represents the electric field, 71,4% of the users answered correctly. 91,4% of the users agree that the answer selected by them is a good representation. The 3 users that didn't agree that it was a good representation, they selected the wrong answer. Meaning that every user that selected the correct representation agrees that this is a good representation. This indicates, that this is a good representation of the electric field.

When asked the same thing about the magnetic field, 51,4% of the users answered correctly. 88,6% of the users agree that the answer selected by them is a good representation. From the 4 users, that said that it wasn't a good representation, 3 selected the correct answer. None of them suggested a way of improving the representation. The fact that almost so many users chose the right representation, as the wrong one, alongside, that some users, even if few, said that this was not a good representation. It indicates that, this representation needs to be improved.

When asked about what happens when the value of the Tension, Intensity and Rotation changes,

the majority of the users, didn't answered correctly.

About tension and intensity a lot of the users, answered what happen in visual terms of the application, for example: "the radius of the circle changes", that is correct for this case, but not for every case, for example if there is a line.

In relation to the rotation, a few users, said correctly, that the e-bean position changes relative to the magnetic field.

We already expected more common wrong answers to this three questions, since the users didn't have to have knowledge in the field of electromagnetism. And that it is hard to learn advanced knowledge of physics, in a 10 minutes experience. However, we are glad, that a few users, could retain some information about the Cathode Ray and how it works.

When asked about what this application was about, 71,4% selected "Electric coils generate a magnetic field", and 65,7% selected "Electrons are manipulated throw a magnetic field", there were two users that selected "Intensity through the coils have no impact on the radius of the circumference" and "Electrons are manipulated throw a magnetic field" and one user "Tension has no impact on the electron beam".

The first two are the correct answers and were the most chosen, showing that most users can understand two important concepts about what the application is about. Notice, that this question, does not show if the user acquired that knowledge when using our application, only that was able to detect them during the game. However, it is still a very good result, showing that the game can show and represent theoretical concepts.

In the end, users where asked if they had any extra feedback, it is important to highlight one answer regarding the game and health of the users. "Please, be aware that some individuals may experience seizures when exposed to this application. An initial warning would be advised".

This is something that we didn't think about, and we will take into consideration in the next development phase.

After analysing all of these answers, we could conclude that this test was very positive, we tested our interface and had very positive results.

Unfortunately, we can also notice that a few users give up before being able to complete the game. In some cases these can be explained by the learning curve of our app, however not everyone like to solve problems and constantly overcoming, which is an important factor in games, i.e., even we flat the curve, that doesn't mean that users will not give up again. As it is possible to see on third objective, that only 8 of 48 users tried to solve the third achievement enough time to receive the hint. All the others users, give up to soon, showing to us, that they were not there interested on complete the game.

Based on EUQ section from the questionnaire, we can conclude that in terms of User acceptance, the app was well received. The points relative to understandable and enjoyable had very positive answers

proving the users understand our UI and enjoined using our app. Also from the rest of the questionnaire, we can notice that the users enjoyed our interface, and understand what they were doing.

For scientific transparency reasons, the data collected in this study can be accessed here[6].

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[6]<https://github.com/Toscan0/IST-Thesis-FaradayMuseum/tree/main/User%20Tests%20Data/WebgGlTests>, Last accessed in 25/11/2020

# 7

# Android App

## Contents

To develop the Android App we had in consideration the work developed in the Chapter 5, and the results of tests presented in Chapter 6.

## 7.1 Extended Play At Faraday Museum

As already mentioned in Chapter 3, this app is a continuation of the work already done by two colleagues. It's an Android App with AR, that allows to interact and learn with the objects. The AR is used to scan the objects, that works as model target.

Our principal objective on this thesis, was to develop an augmented reality interaction with the Cathode Ray artifact with the objective to improve the museum visiting experience.

In this Chapter we will only address work that differs from the WebGL app. Since, the main logic of our app was implemented there and then converted to Android. i.e. We maintend the same app logic and assets, the biggest differences is the UI, that now needs to target a smaller screen and gesture interactions instead of mouse and keyboard.

However, every text showed here is English in our final product it will be in Portuguese, to better target the museum visitors.

### 7.1.1 Android User Interface

Since, our interface was initially designed for computers, i.e., large screens and interactions mainly made by mouse and keyboard. We changed to target the museum tablets. Take in consideration, that at this time, the app will not be available to the users 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 the user uses a really big screen the app will have a lot of empty space, or if uses a really small 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 kept the buttons on the left side, and passed the control panel from the middle of the screen to 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 instead of appearing on the center of the screen now 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 7.1.

In this figure 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.
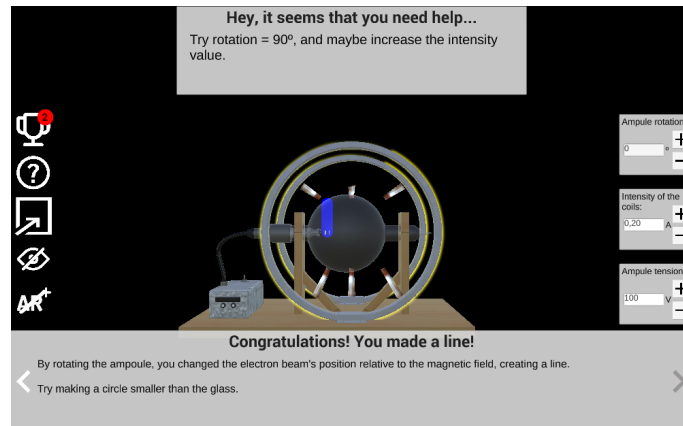
**Figure 7.1:** First version of Android UI.

It is also possible to see, that we decided to remove the slide from the control panel. This decision was based on, that slides doesn't work very well on mobile. We also incremented the size of the button and the input box, to be more easily used by hand touch.

Notice that, we also removed the rotation button, since this rotation is supposed to occur by the user moving around the object with the tablet.

In WebGL the pop-ups had a quit button, however, in Android, we decided to delete this button. Since, it forced the user to click on a certain place on the screen to perform a simple action. In this way, we create a script that closes the pop-up when the user clicks on it. A technique used by many mobile games, such as Archero[1].

After having all this implemented, we did a few play-tests, and it was possible to see, that we didn't had a good contrast between our UI and the museum environment. So we changed the buttons to black, and added the same grey background to the back as the other UI elements. We also darkened the background and removed a little bit of the transparency. In this way, it is still possible to see through but not so much, increasing dramatically the contrast. These changes are possible to see in Figure 7.2;

From the results of the tests done with our WebGL app, Subsection 6.2.1, a user advised us that users may experience seizures when exposed to this application, caused by Photosensitive epilepsy[2]. This may occur in games that have several flashing lights or patterns. To test if our game could create any type of seizure caused by photosensitive, we analysed our game recurring to Photosensitive Epilepsy Analysis Tool (PEAT)[3]. The tool didn't detect any risk, however this tool is designed for web content and not for games, so this results may not be true. So, for discharge of conscience we put a warning in the begin of the app.

To create our warning, we researched how other games do and we did the same (Figure 7.3). From

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[1] https://play.google.com/store/apps/details?id=com.habby.archero&hl=pt_PT, Last accessed in 31/07/2020
[2] https://www.epilepsysociety.org.uk/photosensitive-epilepsy, Last accessed in 12/10/2020
[3] https://trace.umd.edu/peat/help?fbclid=IwAR2hxRGRBBCPXkypiryQuDjnkCGVyjOna9VB2OULRPT3Yd-hTpao3acjOwI,
Last accessed in 12/10/2020
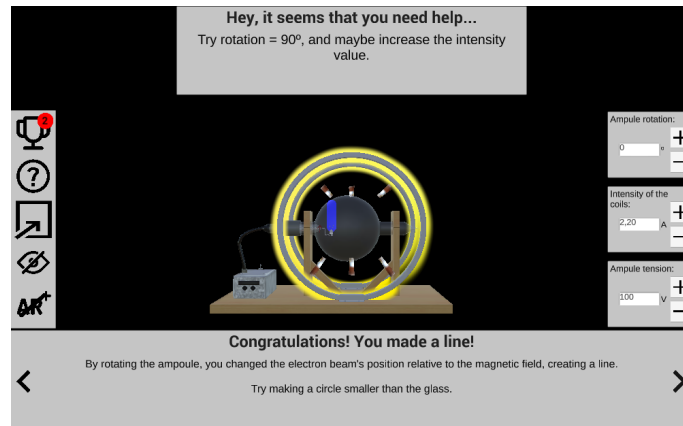
**Figure 7.2:** Second version of Android UI.

our research we noticed, that the warning was always the first thing to appear, and had a title saying: "Warning: Read before play" and the same text talking about Photosensitive epilepsy, the symptoms and what to do. As example we can refer: Trackmania, Valorant, Watch-Dogs 2 and the Playstation[4]. This warning was also added to the WebGL version.
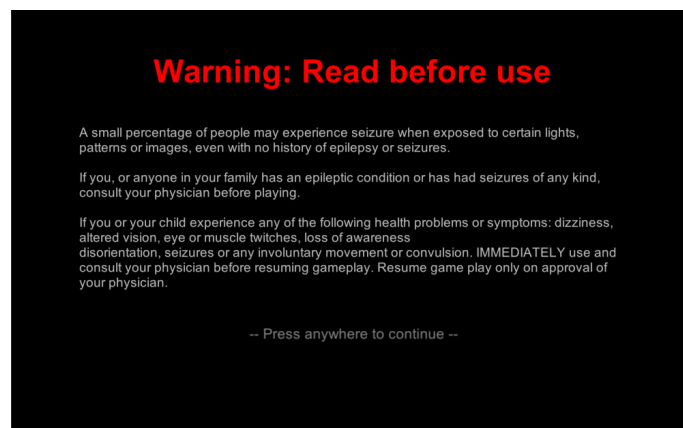


**Figure 7.3:** Photosensitive epilepsy warning

In Figure 7.3 is also possible to see that we changed from a "Play button" to a "click anywhere", that improves the usability of the app. It is also possible to see the final 3D object created by our 3D artist.

The instructions were removed from the start. Since, now the user can interact with more than one object, making no sense to have specific instructions for my object.

We also added a blink animation to the metal box, this animation is triggered every time the user changed the Tension, with the objective to explain the user what value is he changing.

Figure 7.4 presents a screenshot of our application.

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[4] https://www.playstation.com/en-us/network/legal/health-warnings/, Last accessed in 12/10/2020
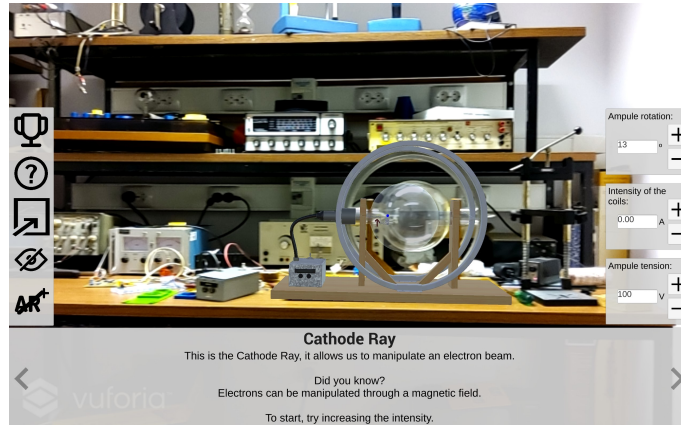
**Figure 7.4:** Screenshot of the application.

### 7.1.2 Bluetooth

To connect our app with the Cathode Ray artifact, and change the data values between them, it is necessary to implement some communication system. For this, it was decided with the museum curators that the data would be received and sent by a Bluetooth Low Energy (BLE) device. The BLE device in question is a hm-10 module, cc2541 chip Texas Instruments[5].

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.

To use BLE in Unity is necessary to use a plugin to handle the connection, we decided to use the Arduino Bluetooth Plugin[6]. This has the advantage of support Bluetooth and BLE and IOS and Android System. Also, this plugin library is simple and easy to use. Since, we only need to send data as a string and receive data as a string, we don't need an hard and complicated library. The only disadvantage that we found, was that this is a paid plugin. However, the free plugins were not enough for what we wanted. Also, we bought this plugin the IST' Game Lab Unity account, so the plugin can be used in more games.

To use this plugin in our project, we imported the plugin and programmed a BLE Manager script. This script handles the connection and implements the function to send and receive the data as a string. When data is received, we parse the data, and check for what artifact the information is referring to. After this, we send the data, for the respective artifact.

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 treat the information, and we calculate the necessary information to draw the respective figure.

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[5] http://www.ti.com/product/CC2541, Last accessed 14/04/2020
[6] https://assetstore.unity.com/packages/tools/input-management/arduino-bluetooth-plugin-98960, Last accessed 14/04/2020

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.

Since the Bluetooth device is not ready yet, to make sure the plugin worked, we created a mobile application[7] and connected with an Arduino with BLE that we had at our disposal. The Arduino device was very simple, and it only had one green led, that we were able to change the opacity, turn it off or on. Our app, had several buttons one slide and one text input, that changed the opacity of the led, from 0 to 255. With this UI, we could simulate the same type of UI elements that we have in our Thesis app.

When the user interacts with one of these elements, the app sends the respective info to the Arduino, that updates the led, and re-sends the info to our app. This simulates the interactions that exist in our thesis app. To test the fact that, the device needs to be able to connect to one BLE device in Luis' work, and to another one in my work, without harming the user experience, we created a way in our app, to change the Arduino that we were connected, that also tests the app if the user chooses to disconnect from the Bluetooth.

## 7.2  Long Term Project Methodology

Following our long term project methodology, we defined several things that should be transversal to all projects. These things, were selected with the help of Luís, and because from the start of the project, regardless of who is programming or the chosen object, these things were always implemented, and already tested by several users, guaranteed in that way, that has a positive impact on them. So, they should continue to be maintained and implemented, regardless of the work being done. And this must be so, so that there is consistency across the application.

These transversal things should be maintained and implemented, regardless of who is programming. So, they should be really easy and quick to add or maintain, i.e., it should be possible to maintain or add, with the less code and changes possible. So, we started working on this aspect.

These transversal things are:

- Adding a new target and the target outline;

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[7] https://github.com/Toscan0/Car_leds , Last accessed in 29/07/2020

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- Adding achievements;

- Adding pop-ups (initial explanation, hints, explanation for each achievement completed and the end of the mini-game and the end-game);

We invested several time researching the best way of adding and modifying these pop-ups. We decided that the best way is using Unity Scriptable Objects. Since this allows, to change the text without changing the code, and to add new pop-ups content, it's only necessary to create a new Scriptable Object witht the respective template, and add this to the respective Scriptable Objects List.

All the necessary templates are already implemented, and the logic that chooses the Scriptable Object to populate the pop-up and show its content is already implemented too. In this way, is possible to create a new pop-up without any line of code. It is also very easy to modify a pop-up. To understand how to make these things, please check our Wiki&How Section present in our Technical Report.

The app already had an easy way of adding a new target, and managing the achievements data base. However, since the Unity Scene has all the artifacts is necessary to distinguish these by each artifact. For this reason, we add an ID field, to all the Scriptable Object, achievements and the targets.

Therefore, programmers can define an ID for their targets and fill the Scriptable Objects or achievements with that ID. All the logic behind is already implemented, so pop-ups and achievements are automatically managed when a target is scanned.

For improvement the readability of the code, in addition to the usual code comments, we tried to follow the best practices guide of Unity [8] as much as possible.

One of this improvements was the adding tooltips to some variables in our code. These tool tips appears when a developer mouse over the respective variable field in the Unity Inspector. As, it is possible to see in Figure 7.5.
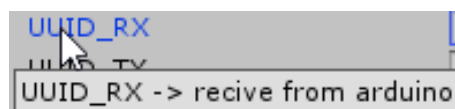


**Figure 7.5:** Tooltip example.

We also, spend a lot of time cleaning the repository, by organizing the folder, deleting the garbage, deleting coded comment that it didn't make sense to keep, deleting unnecessary scripts and standardize names and variables.

Since, every target will be on the same scene, we must try to keep the Hierarchy Scene the most clean and organize as possible. From Figure 7.6, it is possible to see that there are a lot of "Parents" Game Objects, it is hard to find a Game Object, and there are different Game Objects with the same

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[8]https://docs.unity3d.com/Manual/BestPracticeGuides.html, Last accessed in 21/03/2020

name. Also, it is impossible to know which target the game objects are related to, since a lot of the names are not explicit.

So we discussed a way of organize this scene. The way chosen can be seen in Figure 7.7, the Game Objects are organized by types inside of "===" Game Objects, were this have the tag "EditorOnly" so they don't take memory space in the build and consequently on the user's device. They are organized from top to bottom in relation to the possibility of change, i.e., the higher the position the less likely it is to be changed, which improves the visibility while working of the most likely, because they are closer to you.
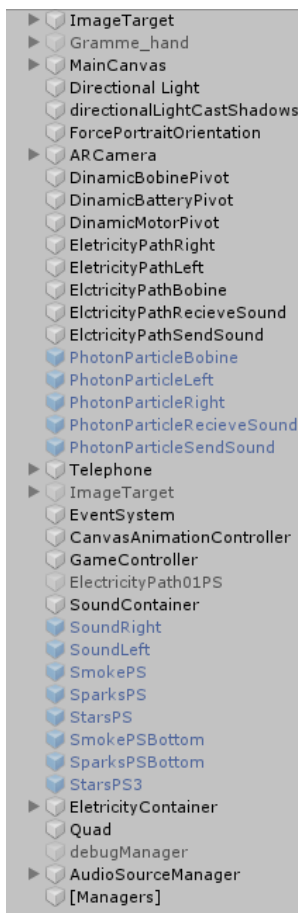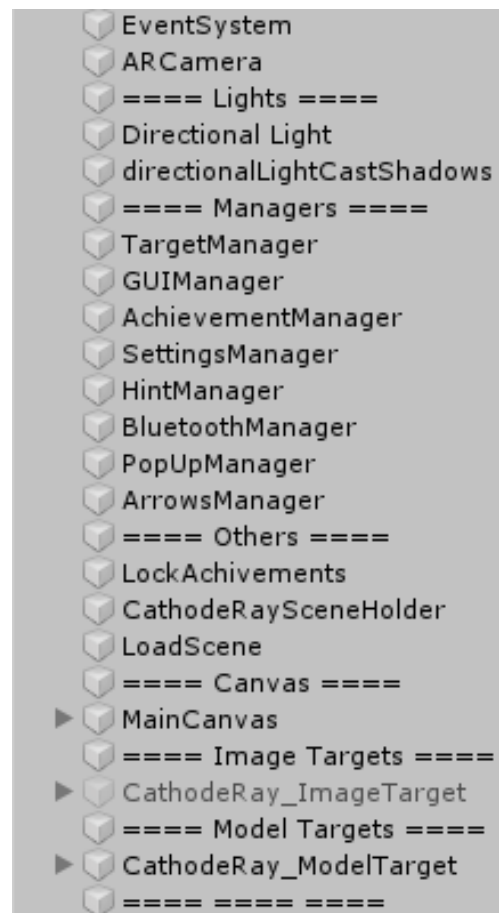


**Figure 7.6:** Old Scene Hierarchy.



**Figure 7.7:** New Scene Hierarchy.

# 8

# Android Evaluation

**Contents**

To develop the Android App we had in consideration the work developed in the Chapter 5, and the results of the WebGL Tests presents in Chapter 6.

## 8.1   Android Evaluation

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.

The main objective of this test was to measure the UX of the app, in terms of acceptance by the user, i.e., if they like to use the app, if they felt the experience was enjoyable, and if they understand our UI. We also wanted to see how the users use our app, in terms of interactions gestures and if they prefer to use the tablet in Landscape or Portrait orientation.

As in the WebGL test, 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 ask them for 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 tests followed all safety requirements for COVID-19 and the same guidelines as the WebGl test. In other words, 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. The questionnaire is a short version of the one used in the WebGL test. It only contains the first tree and the last sections, since the others had the objective to test the UI and the user perception of the application. We also wanted to simplify the questionnaire, since it will be answered on a tablet.

So, the questionnaire had 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 what 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 8.1.1

### 8.1.1 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 whats is going to happen next, since this is AR app, of a physics experience. In the most important points for us: enjoyable, understandable, valuable, supportive, good, easy, efficient, friendly. Where 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, as it possible to see in Figure 8.1 and Figure 8.2 respectively.
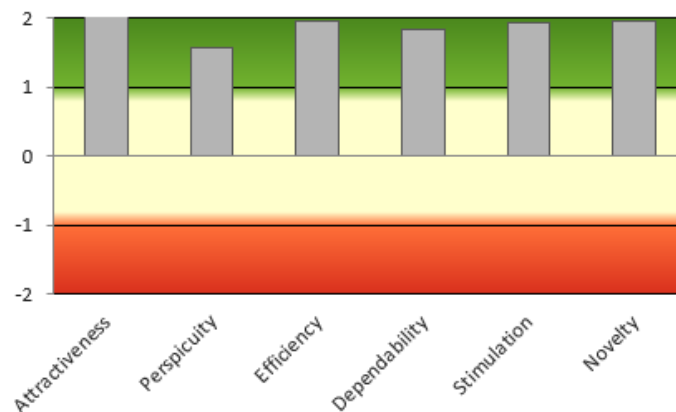


**Figure 8.1:** Android UEQ results relative to the scales Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, Novelty. (Red- bad, Yellow- Average, Green- Good).

Regarding how much we can trust on this values, the Table 8.1, show us the Confidence intervals, were all of them are lower than 0.5%, meaning that all of them are very small and trustful.

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
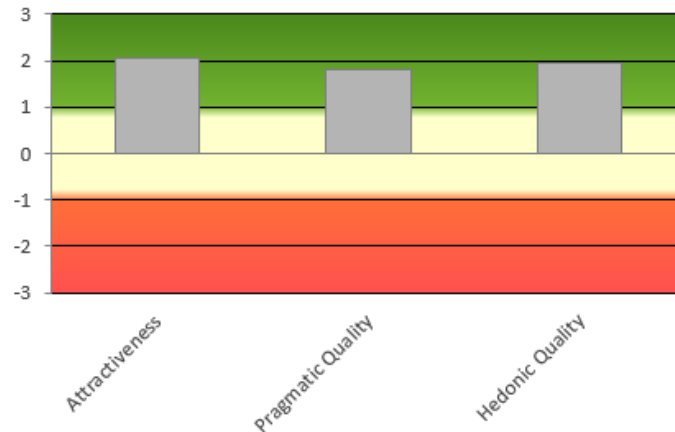
**Figure 8.2:** Android UEQ results relative to Attractiveness, pragmatic quality and hedonic quality.

**Table 8.1:** Android confidence intervals (p=0.05) per scale.

| Scale | Mean | Std. Dev. | Confidence | Confidence interval | |
|---|---|---|---|---|---|
| Attractiveness | 2,067 | 0,784 | 0,344 | 1,723 | 2,410 |
| Perspicuity | 1,575 | 1,133 | 0,497 | 1,078 | 2,072 |
| Efficiency | 1,963 | 0,824 | 0,361 | 1,601 | 2,324 |
| Dependability | 1,838 | 0,828 | 0,363 | 1,475 | 2,200 |
| Stimulation | 1,925 | 0,851 | 0,373 | 1,552 | 2,298 |
| Novelty | 1,963 | 0,808 | 0,354 | 1,608 | 2,317 |

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".

By comparing these results with the results of tests performed with the WebGL app, it is possible to see that we had better results, showing that the changes made to the interface were well accepted by the user.

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 understand that they could move around and get closer or further to see the object from different points-of-view, however there was a 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 a 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 also was being 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, the data collected in this study can be accessed here[1]. The Figures 8.3 and 8.4 present an example of a user testing our application in the Faraday Museum.

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

**Figure 8.3:** User experiencing the application on the Cathode Ray in the Faraday Museum.



**Figure 8.4:** User's point of view while using the application on the Cathode Ray in the Faraday Museum.

# 9

# Conclusion

## Contents

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 that should be implemented in every work. This improvements will facilitate the work of the next student on this app. Due to, COVID-19 we had some difficulties in testing and developing our application around the user opinion, so we developed an WebGl application to easy share our work. The tests done not only show that our UI has good usability but also that the users enjoyed to use our app. These results lead us not only to pass the work done to our Android environment but also to keep improving our WebGl app, so it can stay for posterity, and maybe start an online or virtual reality museum.

In the tests done with our AR Android App we also had extremely good results, where the users showed a lot of interest in our app. 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 in Section 1.1.

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[1] 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.

## 9.1   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 and relate it to the tension/intensity;

- Test the BLE connection with the museum module;

- To decrease the possibility of semantic errors, create a Target ID database;

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[1] https://github.com/ruiprada/FaradayMuseumAR/, Last accessed in 25/11/2020

- 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.

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# A

**Testing Guide**

# Testing Guide

## 1 Objective

The objective of this test, is to evaluate our application, in terms of interface design, easy of use, efficiency, stimulation and understandable. This test also have the objective, to identify the biggest stress points of our application.

## 2 Research Question

With this experiment, we want to answer the following question:

- Did the user understand enjoy using our application?

- There where any stress points?

- If yes, did this stress points make the user give up?

## 3 Setup

In order to facilitate the distribution of the project, the thesis in online in my website. The only setup necessary for the user, is a device (computer is preferable due to the size of the screen) connected to the internet. During the use of the application, we collect the data of the user interaction.

At the start of the application, appears a pop-up asking asking for user consent to participate in our study. The application have a set of objectives, that guides the user throw the use of the application. In the end, a pop-up appears, asking for the user to answer a questionnaire. In this pop-up there will be an button that when clicked, a new tab is open in the browser with questionnaire. The questionnaire have an field that is automatically filled with the log file name, so we can connect the questionnaire with the data collected.

## 4 Procedure

The researchers will contact the potential users, throw social media (IST/LEIC/MEIC facebook group and by direct message to some friends) and subreddits related to game development, if they can test our application, if yes, we send the link of our WebGl application.

Since the museum, don't have a focus group i.e. they have visitors from all ages, genders and with different knowledge about the electromagnetism, any person can test our application. However, since our applications is currently in English, some knowledge of English is necessary.

When the user opens the link, our application is loaded, and after the user agree to participate in our test a pop-up appears explaining what is the object, and giving the first objective to accomplish. There is a set of objectives, that guides the user throw the application. This objectives are:

1. Generate an magnetic field by the electric coils

2. Create a line

3. Create a circumference smaller than the ampule radius

4. Create a circumference bigger than the ampule radius

5. Create a spiral

6. Create another spiral

This objectives where selected, since they cover everything that is possible to do in the real object. They also cover all the physics concepts that this objects allows us to study. The objectives can only by accomplished by this order.

After the final objective, a pop-up appears, thanking the user and asking them to user the questionnaire, there will be a button that opens immediately the questionnaire in a another browser tab.

# 5  Data collection

As said above, data will be collected in two forms. The user interaction data will be collected using our log system, that records the user interaction events (like clicks, drag-and-drops, keys pressed, etc.) in a server. In the questionnaires, we are going to user google forms, that automatically saves the data, and organizes them in charts.

The questionnaire is composed two three parts:

1. Demographic questions: Age, Genre and Academic qualifications

2. Questions about electromagnetism field concepts, and questions about Cathode Ray physics

3. Questions about the interaction with our application:

   (a) A set of questions from the EUQ questionnaire [1]

   (b) A set of questions about what the user thinks about our application and interface

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[1]https://www.ueq-online.org/, Last accessed in 18/06/2020

# 6 Requirements

- **User:**

  - A device (computer is preferable) connected to the internet
  - Browser that allows to run WebGl.
  - Knowledge of English

- **Researcher:**

  - A device (computer is preferable) connected to the internet
  - Since both data are automatically saved in a server, the researcher, doesn't need to be track user test. i.e. he doesn't need to do anything until all the tests are done.

# 7 Data Analysis

To analyse the data, the first step is to remove all the log files and forms that are not connected. After that we are going to use the EUQ tools to analyse the answers given to the EUQ questions present in our form. Next, we are going to parse the log file, since the log files can contain information that is not relevant.

We are going to compare the answers of different demographics users. The log files, will help use, understanding the time spent and interaction between each objective completed. For example if the user spent a lot of time rotating the ampule and changing the intensity values until creates the line. With this, we can understand the stress points, and maybe allows to arrange an justification for the answers given in the second part of the questionnaire.

In the end we will have a set of charts and tables (time, user interaction) that will answer our research questions.

# B

**Questionnaire**

# Cathode Ray Experience

This is an application developed, within the scope of an IST thesis, to improve the visiting experience of the Faraday Museum, one of IST's museums. The application is about interacting with an object of the museum, the Cathode Ray.

The participation in this study is voluntary and it is possible to stop at any time. However, we appreciate your participation until the end.

By continuing, you agree that we keep and use the information for research purposes.

Teachers: Rui Prada and Patrícia Gouveia
Student: João Henriques
*Obrigatório

1.  This space is automatically filled. Please don't change this value. This in a unique ID, for research purposes. *

   _____

   *Avançar para a pergunta 2*

   User Characterization

2.  Gender *

   *Marcar apenas uma oval.*

   ( ) Male

   ( ) Female

   ( ) I prefer not to say

3.  Age *

    *Marcar apenas uma oval.*

    ⬭ <13      *Avançar para a pergunta 43*

    ⬭ 14-18

    ⬭ 19-25

    ⬭ 26-40

    ⬭ 41-60

    ⬭ >60

4.  Academic Qualifications *

    *Marcar apenas uma oval.*

    ⬭ 9th grade

    ⬭ 12th grade / High School

    ⬭ Bachelor's degree

    ⬭ Master's degree

    ⬭ PhD

    Please decide spontaneously. Don't think too long about your decision to
    make sure that you convey your original impression.
    Sometimes you may not be completely sure about your agreement with a
    particular attribute or you may find that the attribute does not apply completely
    to the particular product. Nevertheless, please tick a circle in every line.
    It is your personal opinion that counts. Please remember: there is no wrong or
    right answer!

5.  Select the option that most reflects your opinion about our application. *

    *Marcar apenas uma oval.*

    |          | 1 | 2 | 3 | 4 | 5 | 6 | 7 |           |
    |----------|---|---|---|---|---|---|---|-----------|
    | Annoying | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Enjoyable |

6. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Not understandable | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Understandable |

7. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Creative | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Dull |

8. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Easy to learn | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Difficult to learn |

9. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Valuable | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Inferior |

10. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Boring | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | ⬭ | Exciting |

11. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Not interesting | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Interesting |

12. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Unpredictable | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Predictable |

13. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Fast | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Slow |

14. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Inventive | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Conventional |

15. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Obstructive | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Supportive |

16. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Good | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Bad |

17. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Complicated | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Easy |

18. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Unlikable | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Pleasing |

19. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Usual | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Leading edge |

20. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Unpleasant | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Pleasant |

21.	Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Secure | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Not secure |

22.	Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Motivating | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Demotivating |

23.	Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Meets expectations | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Does not meet expectations |

24.	Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Inefficient | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Efficient |

25.	Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Clear | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Confusing |

26. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Impractical | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Practical |

27. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Organized | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Cluttered |

28. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Attractive | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Unattractive |

29. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Friendly | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Unfriendly |

30. Select the option that most reflects your opinion about our application. *

*Marcar apenas uma oval.*

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 |  |
|---|---|---|---|---|---|---|---|---|
| Conservative | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Innovative |

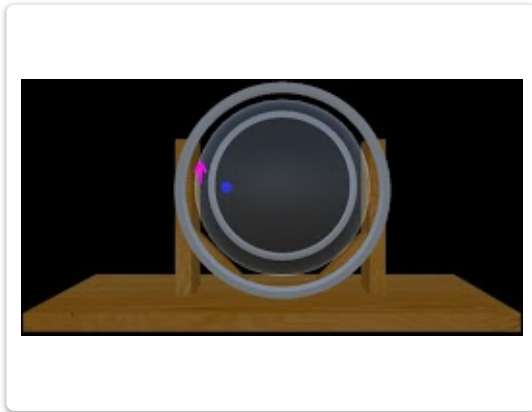31.    Can you indentify the worst part of using our application?

_____

32.    And the best part?

_____

33.    Can you select the image that better represents the **eletric field**? *

*Marcar apenas uma oval.*



◯ Option 1



◯ Option 2



◯ Option 3

34.    Do you think, this is a good representation? *

*Marcar apenas uma oval.*

◯ Yes

◯ No

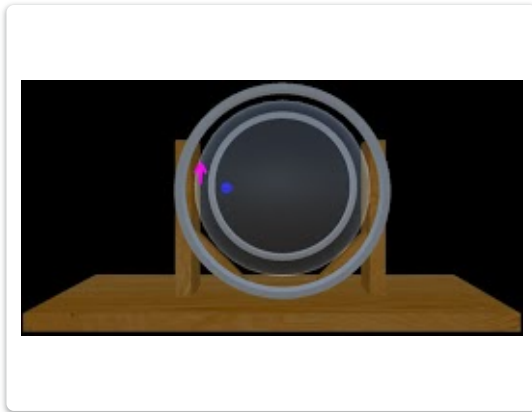35.   If you answer no, please indicate what you would change.

_____

_____

_____

_____

_____


36.   Can you select the image that better represent **magnetic field**? *

_Marcar apenas uma oval._



○ Option 1



○ Option 2



○ Option 3


37.   Do you think, this is a good representation? *

_Marcar apenas uma oval._

○ Yes

○ No

38.     If you answer no, please indicate what you would change.

_____

_____

_____

_____

_____

39.     Can you describe what happens when you change the tension?

_____

_____

_____

_____

_____

40.     Can you describe what happens when you change the intensity?

_____

_____

_____

_____

_____

41.     Can you describe what happens when you change the rotation?

_____

_____

_____

_____

_____

42.   Please select the options that best reflect what this application is about. *

*Marcar tudo o que for aplicável.*

☐ Electric coils generate a magetic field

☐ Intensity through the coils have no impact on the radius of the circumference

☐ Electrons are manipulated throw a magnetic field

☐ Tension has no impact on the electron beam

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We are grateful for the time spent helping us.

If you want to follow our work, you can contact us through this email: j.tiago.henriques@tecnico.ulisboa.pt

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43.   Feel free to use this space to give any extra information that you feel necessary. Every feedback is welcome.

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