DM

MAR Gate
Augmented reality for attracting wider audience to marine concerns

MASTER DISSERTATION

Jocelyne Estefania Pestana Teles
MASTER IN INFORMATICS ENGINEERING

UNIVERSIDADE da MADEIRA
A Nossa Universidade
www.uma.pt

September | 2022

MAR Gate
Augmented reality for attracting wider audience to marine concerns

MASTER DISSERTATION

Jocelyne Estefania Pestana Teles
MASTER IN INFORMATICS ENGINEERING

ORIENTATION
Marko Radeta

UNIVERSIDADE da MADEIRA
A Nossa Universidade
www.uma.pt

Faculdade de Ciências Exatas e da Engenharia

Mestrado em Engenharia Informática

MAR Gate: Augmented Reality for Attracting Wider Audience to Marine Concerns

Jocelyne Estefania Pestana Teles

Orientado por:

Prof. Dr. Marko Radeta

Friday 9th December, 2022

Resumo

As condições nos ambientes marinhos permanecem angustiantes, pois as atividades humanas afetam a qualidade de vida das espécies marinhas. Uma das espécies que sente tais consequências é a Baleia Franca do Atlântico Norte, cuja saúde está em declíneo devido a ameaças passadas e presentes. Uma forma de chamar a atenção para os problemas ambientais marinhos é educando as pessoas, conectando-as a tais espécies, conscientizando-as e fazendo-as refletir sobre ações futuras. Esta dissertação apresenta a aplicação móvel de realidade aumentada, alavancando a interação sobre as Baleias Francas do Atlântico Norte (BFAN), educando os utilizadores sobre a sua contribução para ambientes marinhos, ameaças e curiosidades com essa interação. A dissertação relata o uso de tecnologias imersivas e aprendizagem móvel, fornecendo informações sobre as BFANs. Três estudos foram conduzidos em diferentes etapas do desenvolvimento da aplicação, em ambientes internos, externos e em praças públicas, estudando: (i) como a Realidade Aumentada pode influenciar os utilizadores, (ii) como o público entende as interações e (iii) quão eficaz é a AR para aprender em espaços públicos. Os estudos revelaram as seguintes respostas: (i) a Realidade Aumentada tem um impacto emocional nos utilizadores que pode ser positivo dependendo do tema abordado. A imersão e a absorção são elementos cruciais, e o ambiente externo, seja com sombra ou não, pode não influenciar significativamente na experiência. (ii) Os infográficos sem textos podem ser entendidos pelo público considerando dois factores: a clareza dos desenhos que representam os dados e o conjunto de conhecimentos da população-alvo. (iii) AR demonstra resultados positivos na educação dos utilizadores sobre as Baleias Francas do Atlântico Norte em espaços públicos.

Keywords: Realidade Aumentada · Problemas ambientais marinhos · Aprendizagem móvel · Baleias Francas do Atlântico Norte

Abstract

Conditions in marine environments remain dire as human activities affect marine species' quality of life. Specific species that feel such consequences is the North Atlantic Right Whale, which health is declining due to past and present threats. One way to draw attention to marine environmental problems is by educating people, connecting them to such species, raising awareness, and making them reflect on future actions. This dissertation presents the augmented reality mobile application, leveraging the interaction about the North Atlantic Right Whales (NARWs), educating users about their contribution to marine environments, threats, and curiosities with this interaction. The dissertation reports on the use of immersive technologies, and mobile learning, providing background on NARWs. Three studies were conducted during different stages of the application development, indoors, outdoors and on public squares, studying: (i) how Augmented Reality may influence users, (ii) how the public understands the interactions, and (iii) how effective is the AR for learning in public spaces. Studies revealed the following findings: (i) Augmented Reality has an emotional impact on the users that may be positive depending on the approached theme. Immersion and absorption are crucial elements, and the external environment, whether with shade or not, may not influence the experience significantly. (ii) Public understood infographics without texts if considering two factors: the clarity of designs representing data and the knowledge set of the target population. (iii) AR demonstrates positive outcomes in educating users about North Atlantic Right Whales in public spaces.

Keywords: Augmented Reality · Marine environmental concerns · Mobile learning · North Atlantic Right Whales

Agradecimentos

Agradeço a minha familia, pai, mãe e irmã, que me têm apoiado ao longo do meu percurso académico, sendo os primeiros em acreditarem nas minhas capacidades para concluir esta importante etapa na minha vida académica. Agradecimentos ao meu orientador, o Prof. Doutor Marko Radeta, não só por ser um guia neste projeto senão também por me ensinar que não existem limites para o que queremos ser e que podemos aproveitar os nossos talentos para aplicá-los nos nossos projetos académicos e pessoais. Agradeço também a membros da equipa da ARDITI, com especial menção ao meu colega Pedro Abreu, quem fez um grande trabalho com o desenho e montagem da dome geodésica, ao Rúben Freitas, quem ficou encarregue da base de dados e da página de apresentação e cujas ideias contribuíram imensamente com o trabalho. Agradecimentos ao Andrés Millan por desenvolver a versão iOS da aplicação e ter ajudado desinteressadamente com o projeto aportando ideias e soluções. Também agradeço ao Francisco Silva, que sem ser diretamente parte do projeto, ofereceu ajuda para a montagem da dome e colocar o aplicativo online. Agradeço ao Marcos Silva, Telmo Silva, João Guilherme Câmara e ao Cláudio Rodrigues que em mais de uma oportunidade estiveram ajudando à equipa. Agradecimentos à equipa da Ciência Viva por nos ajudar a encontrar um espaço para o estudo com o público, ao MARE por participar nos estudos e dar sugestões para o projeto. Finalmente, um agradecimento para todas as pessoas que de alguma forma contribuíram com o projeto, seja participando nos estudos, ou simplesmente acreditando no nosso projeto e desejando sempre o melhor sucesso do mesmo. Obrigada.

This dissertation is part of the following projects: **INTERWHALE** - Advancing Interactive Technology for Responsible Whale-Watching, with grant no. PTDC/CCI-COM/0450/2020 by FCT; **LARGESCALE** - Location-based Augmented Reality Gadgets and Environment-friendly Sightseeing of Cultural Attractions for Locals and Excursionists, with grant no. PTDC/CCI-CIF/32474/2017 by FCT and Portuguese National Funds (PIDDAC); **INTERTAGUA** - Interfaces Aquáticas Interativas para Deteção e Visualização da Megafauna Marinha Atlântica e Embarcacoes na Macaronésia usando Marcadores Rádio-transmissores, with grant no. MAC2/1.1.a /385 by Programa de Cooperación INTERREG V-A España-Portugal MAC (Madeira-Azores-Canarias) 2014-2020; This study had the support of FCT through the strategic project UIDB/04292/2020 awarded to MARE and through project LA/P/0069/2020 granted to the Associate Laboratory ARNET. Project has been conducted with the support of the Wave Labs[1] - interactive technologies for depicting the anthropogenic impact on the marine biosphere.

Jocelyne Estefania Pestana Teles

[1] `https://wave-labs.org`

Table of Contents

List of Figures

List of Tables

Lista de Acrónimos

AI Augmented Image

API Application Programming Interface

AR Augmented Reality

BFAN Baleia Franca do Atlântico Norte

GSMA Global System for Mobile Communication Associaton

IDE Integrated Development Environment

ITU International Telecommunication Union

MARE Marine and Environmental Sciences Centre

MR Mixed Reality

NARW North Atlantic Right Whale

NOAA National Oceanic and Atmospheric Administrations

OG Ocean Game

OS Ocean Story

RV Reality-Virtuality

UUID Unique User Identifier

VR Virtual Reality

WDC Whale and Dolphin Conservation

WWF World Wildlife Fund

1 Introduction

1.1 Problem Statement: Low Actions in Protecting NARWs

Marine environments remain in dire conditions. The anthropogenic activity affects the quality of life of marine species, which includes sea pollution [10], noise pollution [11], and heavy and fast ship traffic [12], while marine species are highly likely to be harmed by these problems. The dissertation describes project's design and development using interactive technologies focusing on one of the most endangered species – North Atlantic Right Whale (NARW, *Eubalaena glacialis*). Such species are one of many affected by anthropogenic activity. Currently, the NARW population is estimated to be between 200-250 mature individuals worldwide [5].

Furthermore, the NARW have poorer health because of the lower body condition scores compared to the Southern Right Whales (*Eubalaena australis*) [6]. Indeed, one way to draw attention to these problems is by educating people and connecting them with marine species by raising awareness and reflecting on their future actions that may impact the marine ecosystem [13]. However, the problem with education in marine concerns is that education centers do not widely approach it. The non-formal way faces difficulties in being imparted to an influential audience. Also, both types of education do not include people of non-scholar ages, adults, and the elderly. The challenge is having the broadest possible audience to share a message and raise awareness about marine concerns.

Existing approaches for similar concerns typically use education as it is the key to changing societal processes and attitudes, as Mironenko et al. mentioned [14]. Through knowledge, people can develop a new mental model and skills to face problems in and out of their environment. Still, education about marine environmental issues is imparted formally (being institutionalized, with obtaining a certificate upon completion) or non-formal (programs and initiatives outside the educational system). One of the problems with these two most common forms of education is that the cohesion is slow and incomplete. Although authors have proved that formal and non-formal education has positive results [15], the truth is that most education centers do not adopt it. The education system, in general, has not presented sufficient urgency for the problem of the marine environmental crisis. In the case of non-formal education, it is easier to increase its audience. Still, it often needs to adapt at the same time several factors such as age, occupation, location, and habits, and also, most of the time, this practice requires personnel to teach it.

Motivation. This dissertation is part of the INTERAQUATICA project [16], based on exploring augmented reality for depicting marine concerns. The dissertation will create an augmented reality interface, providing information about the NARW, update the existing augmented reality application ARDome[2] and explore how the audience uses it in a public setting.

Objectives. Tackling marine concerns may be used by leveraging Augmented Reality (AR). The proposed dissertation is an interactive AR mobile application using existing geodesic structures to provide a trigger of augmented images and 3D models of the NARW characteristics. The main goal of these interactions is to keep the users informed, see how they interact, and motivate them to protect the marine environment. App's design will privilege the efficient use by the abroad age group of users (from school-age children to older adults, participants could be teaching staff, non-teaching staff, students, and people outside the academic environment who visit the University or

[2] `https://play.google.com/store/apps/details?id=com.tigerwhale.ardome`

other touristic points of interest). The implemented application is studied in three settings: indoor, outdoor, and open public.

1.2 Proposed Approach: AR for Whales

The thesis proposal is to create an experience related to the NARW based on information about this species. The background consists of an Augmented Reality (AR) interaction where the user uses an Augmented Images (AI) lecture to display three infographics about the species.

In addition, the ARDome application update is a strategy to raise awareness about marine concerns. This app was designed and developed as part of the INTERAQUATICA project [16] and had a Turtle AR interaction already created before the development of the Whale AR modality. The updated version includes both interactions.

This dissertation presents three studies about the effectiveness of the application in educating people about marine megafauna and concerns. The first is placed before the development of the whale interaction modality, with the last version of the ARDome app focusing on the turtle interaction. The second was conducted during the development of the whale interaction. The third one is performed after development of the whale interaction with the updated app, concentrating on the new exchange.

Research Questions. Dissertation explores three core research questions:

- **RQ1**. How AR may influence users while using them in public spaces?
- **RQ2**. How public in general interpret the obtained minimalistic figures without text, and how do they interact with the NARWs?
- **RQ3**. How effective is AR as a conduit for learning about NARWs?

1.3 Glossary

The dissertation uses the following wording, which is presented to the reader for the ease of following:

- **Game engine:** A software framework designed for video game development.
- **Gamification:** The process of including games or gamelike elements (such as tasks) to something to encourage participation.
- **Interoreceptive senses:** The senses that monitor the body's internal state, such as the vestibular and proprioceptive senses [17].
- **Pervasive:**Present or noticeable in every part of a thing or place.
- **Phytoplankton:** A microscopic plankton capable of photosynthesis found in oceans, seas, and freshwater and an essential component of aquatic ecosystems.
- **Ubiquitous:** Being or found everywhere, at the same time.
- **Zooplankton:** A heterotrophic plankton range from microscopic organisms to large species, such as jellyfish.

1.4 Contributions of the author

In this dissertation, the reader may notice that the project's development is the result of the efforts of a team that performed various tasks. Naturally, the author of this dissertation is a member of the mentioned team. Therefore, these paragraphs briefly explain the author's contributions to the ARDome app and MAR Gate studies.

The author participated in the studies with responsibilities such as inviting people to participate and delivering questionnaires (Study A). Guide the study flow with questions and show images to the public (Study B). Observe general public reactions while approaching and interacting with the dome structure (Study C). The details of these activities are in Section.

While developing the project, the author designed some of the Augmented Images and pictograms. In this dissertation, the images have the corresponding author on the captions. Consequently, the reader will identify them without effort.

The app programming on Android's operative systems was another contribution of the author of this dissertation. All these details are in Section.

1.5 Structure of the Document

- *State of technology (Section 2):* The topic of this section is related to the technologies that work with Augmented Reality. The chapter presents subjects such as Sensorama's history and the difference between Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR). Lastly, the reality-virtuality spectrum demonstrates the broad future of the devices that play with the natural world and our perceptions.
- *Mobile Learning (Section 2.6):* This section is dedicated to the learning process using mobile devices, including the history, implications, perspectives, problems, resolutions, foundations, and other related subjects.
- *North Atlantic Right Whale (Section 3):* As the project is directly related to this species, this section additionally serves to inform the reader about NARWs' life, distribution, threats, and more.
- *Methodology (Section 4):* The chapter explains all the processes in the development of the AR application and describes the studies made to validate the impact of the application on the users in three experiments.
- *Results (Section 5):* The results of the studies explained in the methodology (section 4) are presented in this section.
- *Discussion (Section 6):* A reflection about each study is exposed in this chapter.
- *Related work (Section 7):* This section includes relevant studies with similar objectives or procedures to this project, including findings comparisons. This information is placed after the methodology, results, and conclusion sections to give the necessary information about the project and ease comparisons with the related works.
- *Conclusion (Section 8):* A summary with the most relevant points and final thoughts about the dissertation is depicted.

– *Attachments (Sections 9, 10, 11 and 12)*: These attachments contain code of the integrated features for the ARDome application, questionnaires used in Study A, demographics of the participants in Study A, and quizzes questions of Study C.

2 State of Technology

For this project, the dissertation considers technologies that work with augmented realities. The section further provides the analysis of state-of-the-art applications.

2.1 History of the reality-related technologies

Reality-related technologies such as Augmented Reality or Virtual Reality have a common ancestor created decades ago. "*Sensorama Simulator*" [18] was the name of this device, developed by Morton Heilig at the end of the 1950s decade in the United States. This machine consists of a system of a 3D-video component that was composed of three coupled 35 mm cameras, stereo sound, a vibrating seat, wind, and smells with the help of fans located near the user's head [3]. The goal of this machine was to play with all user senses to create an immersive experience. Users could find *Sensorama Simulator* (Fig. 1) in popular fairs.

Fig. 1: Picture of the Sensorama Simulator.

In the following years, Ivan Sutherland invented the first 3D headset in 1968. Myron Krueger created the first multisensory interactive environment in 1969. Thomas Zimmerman and Jaron Lanier were the creators of *DataGlove* in 1985 [18]. These inventors triggered the natural interfaces research and development. Technology that involves more natural interactive systems is different from mechanical ones, such as the mouse, monitors, and keyboards.

2.2 Augmented Reality

Definition. Augmented Reality, better known by its acronym, AR, is the real-time enhancement of the real world by adding virtual computer-generated elements that can be observed directly or indirectly. The objects in the environment can be registered, and the virtual ones can be placed on them.

[3] Interview with Morton Heilig explaining *Sensorama* features and limitations (1980): `https://www.youtube.com/watch?v=vSINEBZNCks`

Purpose and examples. AR is defined as the merging of 3D virtual objects with the real-world environment. The purpose of AR is to enhance the user's perception and interaction with the real world. Displays do not restrict it, and AR can apply to all senses [19]. *Sensorama* was an example because it played with 3D vision, smell, and touch. Indeed, AR can potentially help people with missing senses by sensory substitution. Users with limited vision can use AR to augment their sight with auditive components. In contrast, AR can help deaf people with visual assistance [19]. Augmented Reality's utility is centered on giving users information not possible to detect in the environment with their senses. These characteristics have advantages in performing daily tasks. The workers can receive additional information about the mission and environment status through AR. For example, mobile augmented reality for medical training [20], maintenance, and repair [21], marketing [22], education [23], etc.

Entertainment is another fundamental approach to Augmented Reality [19]. The most relevant example is the popular game *Pokemon Go* [4]. This game (Fig. 2) was the first contact with an AR system for most people worldwide because of its accessibility.

Fig. 2: Capture showing Pokemon Go's AR feature.

AR in mobile systems. Developers design AR systems considering mobility. AR mobile systems include wearable mobile devices that allow users to interact with digital information merged with the natural environment. The objectives are to enable users to keep the focus on the application and provide users with private data with the possibility of sharing. In the case of the devices,

[4] Video demonstrating how AR works in the *Pokemon Go* game: `https://www.youtube.com/watch?v=yUNtfM1CIPU`

the desirable characteristics are lightweight, wearable or mobile phones, socially acceptable, and private and robust tracking technology [19].

2.3 Mixed Reality

Definition. Even in current times, Mixed Reality's (MR) definition is challenging to understand because we are far from a shared concept of what MR means. Researchers generally base their definitions on Actual Reality and Virtual Reality Continuum (a topic that the thesis will approach in the following sections). Speicher et al. [24] made an extensive investigation. They found it necessary to identify different definitions used in related fields, analyze how they differ and connect, and explain the limitations in defining what MR is. The authors compiled six widely used working definitions of MR according to different notions.

- **According to Continuum:** MR is defined as a mix of real and virtual objects within a single display on a spectrum between a fully real and a fully real world.
- **As a synonym:** The authors found several papers that treated MR simply as a synonym for AR.
- **As a type of collaboration:** MR is the interaction between AR and VR even when their users are physically separated. This notion includes the mapping of spaces. For example, two users are in different rooms, one using AR registered the surrounding environment while the other with VR visualizes the same environment being virtually reconstructed.
- **As a combination of AR and VR:** The MR system combines some aspects of AR and VR and makes them interact without tightly integrating them. Another way to explain Mixed Reality considering this notion is the capability of switching between VR and AR in the same application.
- **As an alignment of environments:** This notion is similar to the last two in this list. The settings are not physically separated for the two users (like the idea of collaboration explains), and the system combines different physical and virtual parts. Still, the environments do not necessarily have to be AR and VR (like in the notion of combination). In other words, it is an alignment of a virtual representation with the real world.
- **As a "stronger" version of AR:** MR is an AR with more functionalities that it cannot offer on its own. MR is bound to specific hardware or device that can provide those functionalities. This notion presumes that MR is an evolution of the "regular" AR.

Purpose and examples. Mixed Reality has similar purposes to AR. There are examples of interactions between the Solar System and Plant System developed for classrooms and self-learning in education [25]. Nowadays, museum visitors can use MR to visualize ancient art pieces in their original state (Fig. 3). Users can obtain extra information about the restored parts of the article and what part is missing with a recreation of the complete sample [1].

Medicine students can resort to MR to practice their skills safety. Doctors use MR mobile version for teaching procedural skills, anatomy, and clinical assessment [26]. Researchers proved MR is even more effective than traditional 2D architectural design in communicating building characteristics with clients [27]. There are more examples of MR usage. The ones presented in this section are the more relevant ones. Naturally, there are more areas where the MR is employed, such as robotics [28], sea transport [29], and aviation [30].

Fig. 3: Example of the Athena Parthenos enhanced digitally. The spear is added virtually, and the blue parts are the restored ones (retrieved from [1])

2.4 Virtual Reality

Definition. Some researchers defined VR using three characteristics: presence (or telepresence), interactivity, and immersion [31].

- **(Tele)presence:** The feeling of being physically in another place where the person is staying is not the one.
- **Interactivity:** The property allows users to manipulate their virtual environment in real-time.
- **Immersion:**This characteristic can be measured by inclusiveness, extensiveness, surrounding, vividness, and matching.
  - *Inclusiveness:* The range in which reality is excluded.
  - *Extensiveness:* The range of sensory modalities was addressed.
  - *Surrounding:* The field of view's size.
  - *Vividness:* The display's richness, resolution, or quality.
  - *Matching:* The characteristic allows the users to feel that their body movements are aligned with the displayed virtual information.

  Another version of immersion's definition is related to emotional involvement. The theory includes cognitive, emotional, sensory-motoric, and spatial immersion.
  - *Cognitive immersion:* Solving complex problems can offer users an immersion sensation by focusing on them.

- *Emotional immersion:* Users feel engaged with the narrative.
- *Sensory-motoric immersion:* Feedback about users' movements can help with immersion.
- *Spatial immersion:* Users feel when they perform extensive maneuvers.

Therefore, there are three definitions for Virtual Reality given by different researchers [31]:

– VR is a group of devices that enable people to experience an immersive world beyond reality.

– VR is an environment created by the computer that can be experienced and interacted with as if it was real.

– VR is a real or virtual environment where a user perceives it as telepresence.

The Emeritus Professor of Educational Technology at Howard University, Gabriel D. Ofeisch, expressed an essential distinction of VR from other technologies: "As long as you can see the screen, you're not in virtual reality. When the screen disappears, and you see an imaginary scene, you are in virtual reality" [31].

Purpose and examples. Nowadays, many companies use VR for education, retail, transportation, energy, consulting, insurance, healthcare, and sports [31]. The approached subjects in **education** can be anatomy, geography, history, physics, and chemistry. *VR Immersive Education* and *Google Expeditions* are examples of VR educational experiences. In **retail**, *IKEA* employs VR to instruct new employees. *Macy's* takes VR to improve customers' experiences while shopping. *Verizon* trains its store workers with VR to handle hostage and robbery contexts. In **transportation**, *Deutsche Bahn* has the idea of using VR training for scenarios that are impossible to teach on real trains. *Volkswagen* uses VR for prototyping and *Tata Motors* to configure cars with their customers. *Energy* companies such as *E.ON* uses VR to instruct substation employees. *Shell* trains personnel for deep-water oil projects using VR for safety. *MHI Vestas* uses it as a sales tool to display offshore wind turbines. In **consulting**, enterprises like *Accenture* use VR to evaluate workers, *PwC* conducts diversity and inclusion training through VR, and *BDO* employs VR to test personnel recruitment. *Farmers Insurance* ideate to conduct interpersonal skills training in VR, and *Cigna* employs VR to perform health screenings and pass health information to customers. *PNB MetLife* consults with their clients are examples of VR uses in **insurance**. *Harvard Medical School* and *Columbia University* employ VR to train surgeons in **healthcare**. *Takeda* uses VR recruitment. *Ivoclar Vivadent* proposes using VR to distract patients during dental treatments. VR is used even in **sports**. The *Dallas Cowboys* started training their players in VR. *Premier League* teams use VR to identify soccer talent. *NASCAR* employs VR to allow fans to experience racing events remotely.

2.5 Reality-Virtuality Continuum

How to distinguish virtual from real? Before explaining the reality-virtuality spectrum, it is crucial to understand the differences between real and virtual objects. Milgram et al. offered a clear explanation considering three different aspects. Following Fig. 4 will help to understand the distinctions between the three aspects.

Real Object vs. Virtual Object: On the left of Fig. 4, it is possible to observe a representation of virtual and real objects. Real objects have an objective existence, and virtual ones exist in essence or effect but not formally or actually. Viewing a real object can be done directly or

sampled and synthesized via a display device. The computer must simulate virtual objects because the user can't observe them.

Direct Viewing vs. Non-direct Viewing: This distinction involves the case of image quality as an aspect of reflecting reality. The measure for realism is taken as direct viewing (through air or glass) of a real object. This type of viewing is also called "unmediated reality." If the real object is observed using some imaging system first to sample data about it, using a video camera, laser, or ultrasound scanner, for example, and then is reconstructed via a display medium, like a video or computer monitor. The computer can only synthesize virtual objects. In Fig. 4, the non-direct viewing of real or virtual objects is represented as a presentation via Synthesising Display. The point here is not to differentiate natural objects from virtual ones since synthesized images of non-real objects can look very realistic. The authors intend to consider that a represented object is not necessarily real because it "looks realistic." For that reason, the terminology must be able carefully to reflect the difference.

Real Image vs. Virtual Image: In the field of optics, a real image is any image that has some luminosity at the location at which it appears to be located. This definition includes a real object being observed with direct or non-direct viewing (through a display). A virtual image is an image that has no luminosity at the location it appears, for example, holograms and mirror images. In Fig. 4, there is a stereoscopic display. The left and right eye images are authentic, but the fused percept in 3D space is virtual. In the MR spectrum, virtual images are transparent, i.e., does not occlude other objects located behind them.

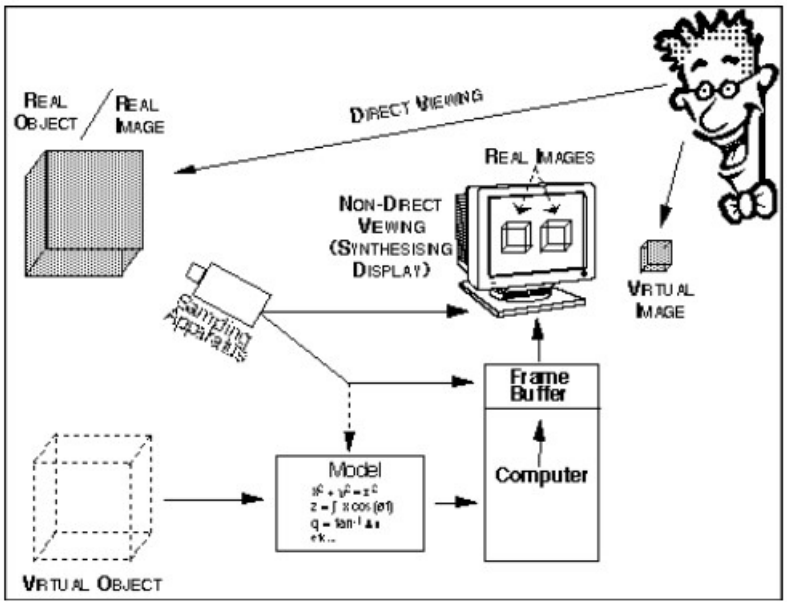


Fig. 4: Scheme used by Milgram et al. to exemplify the distinction of reality from virtuality: Real vs. Virtual objects, Direct vs. Non-direct viewing, and Real vs. Virtual image (retrieved from [2])

Definition of RV Continuum. One of the first and most referenced definitions of the Reality-Virtuality Continuum is from Milgram and Kishino's research and works in the 1990s. Skarbez et al. recently revised Milgram et al.'s work and suggested an updated version, considering the

technological progress in almost 30 years. This section will look only at the definitions presented by both research groups to understand how the point of view changed through the years.

Milgram et al.'s point of view. Milgram et al. [3] mentioned that AR and VR are related, and somehow it is correct to consider both concepts as parts of a general one. Reality-Virtuality (RV) is a spectrum with two extremes: the real and the virtual environment, as the figure presents (Fig. 5). On the left is the natural environment, which consists of real objects, and can be observed directly or through some kind of display (e.g., a video camera). On the right is a virtual environment that only possesses virtual objects, such as the usual computer graphic simulations, either monitor-based or immersive [5].

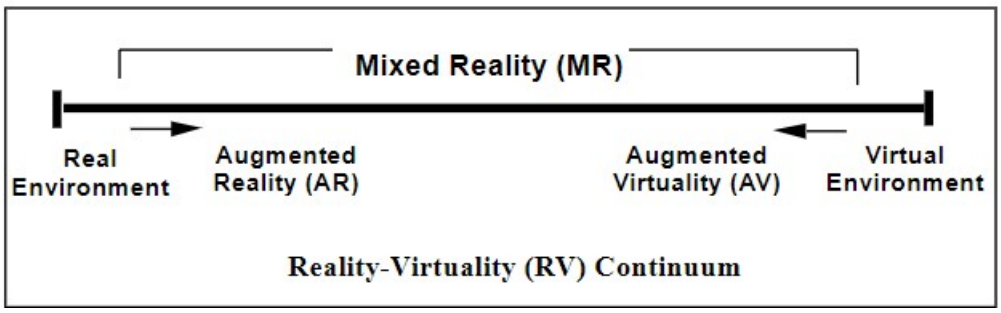


Fig. 5: Simplified representation of a RV Continuum (retrieved from [3])

Skarbez et al. revisited version. Skarbez et al. [17] found limitations in the Milgram et al.'s definition. Milgram and Kishino focused on visual displays and their hardware, i.e., other users' senses are not considered in the definition, only the vision. Furthermore, the content was described uniquely as realism, not considering the coherence of the experience in general. It is possible to consider audio signals, haptics, scent, and taste with today's processor speed. Even in the 1960s, these possibilities were presaged with Sensorama [18]. Another point is the hypothesis of the *Ultimate Display's* existence. The authors who revisited Milgram's work mentioned if it was possible to have the most advanced display, it still fit within the realm of MR. Even if the device controls the user's external senses (vision, smell, haptic, taste, hearing), it still doesn't have control over the interoceptive senses [6]. In addition, an Ultimate Display's existence would cause conflicts between the interoceptive and external senses. However, the authors believe that a technology offering such immersion in a virtual environment is unreachable. Consequently, Milgram et al. considered that the concept of RV is continuous. Still, the technology will never reach that point of a completely virtual environment, and this means that RV is, in fact, discontinuous. This discontinuity is reinforced because any form of technology-mediated reality is mixed.

Having explored three technologies that are part of Reality-Continuum, such as AR, MR, and VR, the selected one for this dissertation was AR. Besides the low cost, another reason is less heavy than other technologies mentioned before. AR is present in mobile phones, so we allow users to use their devices. MR and VR need head-mounted displays, which are inappropriate for open

[5] Notably, Milgram et al. considered Mixed Reality (MR) as the environment in which real-world and virtual-world objects are presented together within a single display. In the spectrum, MR is placed between the real and virtual environment.

[6] **Interoreceptive senses:** The senses that monitor the body's internal state, such as the vestibular and proprioceptive senses [17]

public spaces due to the need for plugs and sockets to work. Additionally, using a wired device depends on personnel to be there for the device's security; consequently, the sensation of doing the experience freely may be perturbed.

For this dissertation, AR will be used to provide novel interactions with existing geodesic structures to create a mobile learning experience, which is a new contribution combining reality-related technology with this educational modality.

2.6 Mobile Learning

Since this dissertation aims to create an experience where the users can interact while learning about the whales using a smartphone and an AR app, research on the relationship between mobile phones and education is necessary to understand it.

History. In the late 70s, the Xerox Dynabook project proposed an independent, separate and complete knowledge manipulator in a portable package with the size and shape of an ordinary notebook, allowing children to explore, create and share dynamic games and simulations [32]. After the Xerox Dynabook project proposal, innovations were desktop-based. Then from the early 2000s, mobile learning has developed as a set of significant projects in schools, workplaces, museums, cities, and rural areas worldwide. Sharples et al. wrote this paper [32] in the age of personal and technical mobility, where mobile devices, including phones, MP3 players, and PDAs, were carried everywhere. Nowadays, the most common device carried by people is smartphones, followed by tablets and laptops.

What is mobile learning? The critical success of mobile learning impacts its concept, leading the communities to define it depending on their particular view based on their experiences. Consequently, several theories and perspectives have appeared through the years of research. As the "mobile learning" concept has multiple versions, it is difficult to characterize and currently is considered ill-defined. For that reason, a re-conceptualization is necessary to define the precise nature of mobile learning [4].

Perspectives. Four categories [4] exist to characterize mobile learning based on the current perspectives:

- **Technocentric:** It is the most popular approach in literature. It is learning with a device such as a mobile phone, PDA, or iPod, among others.
- **Relationship to e-learning:** Mobile learning is an extension of e-learning. This definition combines both concepts, mobile learning and e-learning. Consequently, it doesn't help to clarify what mobile learning is. According to Traxler (2005), the technocentric and e-learning concepts place "mobile learning somewhere on e-learning's spectrum of portability."
- **Augmenting formal education:** Generally, the literature defines formal education as the typical face-to-face lecture. Nevertheless, this perspective is not completely clear or correct. In the words of Peters (1998), education, where the learners and teachers are in different places (for example, using communication via letter), has already existed for over 100 years. For that reason, this leads to questioning the definitions given about formal education.
- **Learner-centred:** Winters et al. [4], in 2002, defined mobile learning as a concept significantly linked to devices. Nevertheless, at the following times, the definition was centered on the mobility of the learner. Consequently, mobile learning is "any sort of learning that happens

when the learner is not at a fixed, predetermined location, or learning that happens when the learner takes advantage of learning opportunities offered by mobile technologies" - O'Malley et al. (2003).

Analysing the problem. During a workshop presented by the Kaleidoscope Network of Excellence Mobile Learning Initiative [4], Winters et al. registered four critical characteristics of mobile learning that are cited in the following list:

- Enables learning building by students in different contexts.
- Enables learners to construct understandings.
- In many cases, mobile technology changes the learning/work activity pattern.
- The circumstances of mobile learning are about more than time and space.

Another great point is that for learning-oriented mobile applications to be innovative, they should not pay exclusive attention to information transmission and keep their distance to a model of "anytime, anywhere" access. Based on the premise of mobile learning as an intervention in terms of guiding what the learner is constructing, workshop participants established more key points through an activity consisting of scenario-building. These key points are cited in the following list:

- **The relationship between the learner, teacher, and parent/caregiver is essential:** This affirmation is relevant because it helps to structure the interaction between the technology that is the property of the student and the activities in formal education.
- **Mobile applications often afford cross-curricular activities:** One of the advantages of engaging with teachers by using mobile technology as a tool for classroom activities.
- **The ethical dimension is critically essential:** As humanity is moving towards a time where ubiquitous technology is everywhere, this concern emerged multiple times in the workshop discussions.
- **Representation on the mobile device is an issue:** Mobile devices are well known for their small-screen size, and it constitutes a challenge in representing the content that learners will use.

Implications. Additional implications of mobile learning are described as follows:

1. Mobile learning applications are best viewed as mediating tools in the learning process. It means that they are not limited to themselves and can be extended to other learning tools that teachers and students already possess or future tools that will appear with technological advances.
2. Three factors support the design of mobile learning activities:
   - Relationships between the learner, colleagues, teacher, etc.
   - The topic that the learner is learning.
   - The place and context where the learner is learning, and the topic's relation to them.
3. Considering the three factors of the last implication, the application's design will form the basis for a distributed learning network, which can be part of other learning tools, activities, contexts, and people dispersed over time and space.

Resolution. Winters et al. stated that, after the group dialogue, they build a concept map with crucial characteristics to re-conceptualize mobile learning. The final version of the map is in Fig. 6.

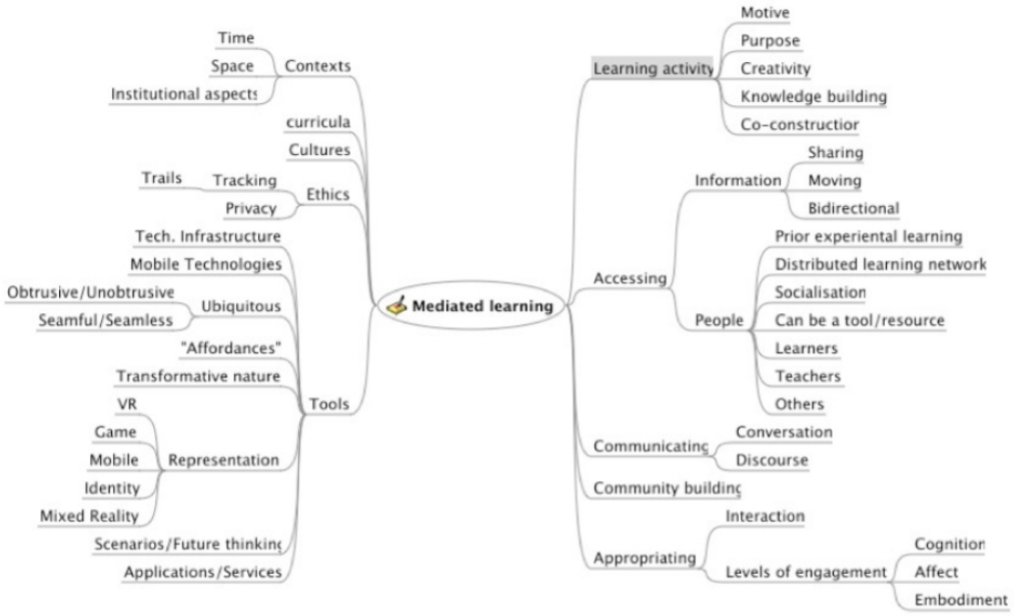


Fig. 6: Final version of the concept map done in the workshop (retired from [4]).

In the center of the map, the concept of mediated learning takes place instead of mobile learning, as we could expect. That means that technology takes a secondary role. The importance is to determine the nature of the application based on social factors and activities. Therefore, we have new ways to leverage technology in new and exciting ways.

Why is it called "mobile"? According to Sharples et al. [32], the word "mobile" in mobile learning results from five ideas referenced in the following list:

- **Mobility in physical space:** For learners, locations are either a relevant element to the learning process or merely a backdrop.
- **The mobility of technology** refers to portable devices that a person can carry easily. Also, the users' attention can be transferred across devices if required. For example, we are moving from the smartphone to the computer or the tablet.
- **Mobility in conceptual space:** When a person is learning topics and themes, shift the attention between them. An average adult has at least eight major learning projects a year with numerous daily learning episodes. In conclusion, concentration depends on the interest, commitment, or curiosity that the person has about a particular topic, which flows from one subject to another.
- **Mobility in social space:** Learners can share the learning process in a social context. For example, with family, with office or classroom colleagues.
- **Learning dispersed over time:** To understand is necessary to connect and reinforce the different learning experiences through formal and informal contexts.

Another point of view. According to Kukulska-Hulme et al. [33], the concept of the mobile learning approach existed before it started to be related to mobile devices. Essentially, learning outside the classroom is, to some extent, to have the motivation to do it wherever and whenever the opportunity happens. Portable devices came to mobile learning as new tools to facilitate it. These devices help in communication and collaboration, and their lightweight and portability facilitate the "transport" of the learning content. They permit education occurs differently than other educational media allow. As another advantage, some of these devices are low-cost compared to the usual desktop computers and are more spontaneous and personal. Using the Internet, they can offer comprehensive educational resources. To summarize, mobile learning has a list of attributes that helps to describe it. In the words of Kukulska-Hulme et al. [33], those attributes are spontaneous, personal, informal, contextual, portable, ubiquitous [7], and pervasive [8]. These attributes make mobile learning similar to other e-learning devices, such as computers. However, the difference is in the advantages of permitting location changes and immediate interaction, as these devices are primarily wireless and small.

Foundations. Researchers in this area study how the mobility of learners augmented by personal and public technology can help them learn new topics and gain skills and experience. The objective is to analyze the mobility and contexts, assuming that learning not only occurs within a fixed location in a specific schedule, i.e., but also flows across locations, time, topics, and technologies [32]. The use of technologies while learning has the advantage of allowing the users to keep their long-term projects on their devices, which are familiar to them. Furthermore, these mobile devices help save circumstantial ideas as the learners progress during their learning process.

Context. The key to mobile learning is the context created by people interacting with more people, including the space and other tools. Traditionally, learning spaces are exclusive school classrooms, giving a stable context. However, if those elements are removed, the challenging part is to know how to create moments of stable context and permit the continuity of the learning flow. Based on Dewey (1916), Pask (1976), and Stahl (2003), Sharples et al. [32] proposed that to understand the world, we need fundamental processes such as exploration, conversation, and collaborative knowledge building.

- **Exploration** is a process that is essentially mobile because it implies movement, either physical or through conceptual space. It connects experiences and concepts into new knowledge.

- **Conversation** links learning within and across different contexts. Learners form new ideas through discussions with the participants within the same place or, as the opposite, each one in different and distant places using phone calls, for example. In addition, portable devices allow for taking notes for future reference. Consequently, it is possible to record relevant parts of the conversation.

- **Collaborative knowledge building** results from technical assistance in these explorations and conversations. The technology's roles include forming a distributed system of meaning-making that promotes collaborative knowledge building.

[7] **Ubiquitous:** Being or found everywhere, at the same time (`https://www.wordreference.com/definition/ubiquitous`)

[8] **Pervasive:** present or noticeable in every part of a thing or place (`https://dictionary.cambridge.org/dictionary/english/pervasive`). In this context, mobile learning is so integrated with daily activities that are hardly notice [33]

Technology in learning. Nowadays, technology is an element that accompanies and guides the learner, continuously monitoring the performed activities. It allows for storing exploration progress and the conversations done by the learners. Then those records can be accessed later to consult the achievement and recall the topics already learned. According to Sharples et al. [32], conversation and context are essential for understanding how educational members can integrate mobile learning with conventional education. With these explored foundations, the conclusion is that mobile learning can offer new practices to extend teaching outside the classroom, using the conversations and interactions of daily life.

Theories behind mobile learning. As observed in the workshop described by Winters et al. [4], conceptualizing mobile learning was a problem. Sharples et al. [34] told that problem about two years before. The notable point was specifying the role of mobility and communication in the learning process. Therefore, the researchers recognized the importance of the context and the essential role of technology in going beyond age and culture barriers. Behind the design of new applications and technologies to support mobile learning, a lot of analysis exist. Designers need to know the tools, their utility, and constraints when assisting learners. Therefore, it is necessary to consider two perspectives (called layers by the researchers [34]):

- **Semiotic layer:** Explain learning as a semiotic system in which the learner's object-oriented actions (i.e., actions to promote an objective) are mediated by cultural tools and signs.
- **Technological layer:** Represents learning as involvement with technology. Mobile phones and computers work as interactive tools in the learning process. It creates a human-technology relationship where the importance of maintaining communication, mediating agreements between learners, and the possibility of recalling and reflecting on concepts are present.

Theory steps. Authors determine a group of steps to theorize about mobile learning [34]. First, it is necessary to distinguish what is unique about mobile learning compared to other varieties of learning activities. Evidence is that this type of learning lets learners be on the move. Mobility not only means a "physical move," it means that we can learn across locations, time and topics. Indeed, school students have mobility, too; they go from one room to another and pass from one topic to another during their learning time. Therefore, the object of analysis should be the transference of knowledge and skills through contexts. The second step is to understand that people are the one who initiates and structures the activities outside the classroom. Sharples et al. [34], found the most common context for adults' daily learning. In the first place, we found the house or the office as a place where adults reported they have more learning episodes, with 51%. Other places are also their workplace but outside the office (21%), locations such as places of worship, hospital waiting rooms, cafes, hobby stores, and cars (14%), outdoors (5%), in a friend's place (2%), and places of leisure (2%). Surprisingly, only 1% of adults report transport as their place of learning. Thirdly, the theory must be based on modern practices that enable successful learning. Accordingly, researchers at the US National Research Council synthesized a study about the educational effectiveness across ages and contents of different areas. That study concludes that effective learning is learner, knowledge, assessment, and community-centered. In the following list, these concepts are justified:

- **Learner-centered:** The learners have skills and knowledge after understanding a topic and let their reasoning be based on their own experience.
- **Knowledge-centered:** The curriculum is conceived from the valid basis of corroborated knowledge. It is taught efficiently and with the ingenious use of concepts and methods.

- **Assessment-centered:** The students' ability has to be matched with the assessment. It allows diagnosing and guiding the learner to good results.
- **Community-centered:** A community that promotes, shares knowledge, and supports learners contributes to their success.

The last step is to consider the ubiquitous use of personal and shared technology. In the UK, over 75% of the population and 90% of young adults owned mobile phones in 2003 [34], according to the researchers. However, it is relevant to use more recent and general data.

The Global System for Mobile Communication Association (GSMA) found that 4.7 billion people were using mobile phones, and by 2020 this number will rise to 5.6 billion. According to the International Telecommunication Union (ITU), there were 7 billion mobile subscriptions in 2015, 780 million more than in 2000 [35]. This means that mobile phones are one of the most spread technology worldwide.

Theory criteria. Considering this information and steps, researchers determined these essential questions to test a mobile learning theory:

- Is it considerably different from current theories of the school room, job site, or learning lasting a lifetime?
- Does it justify the mobility of learners?
- Does it extend formal and informal education?
- Does it theorize knowledge as a constructive and social procedure?
- Does it analyze learning as an individual and situated activity mediated by technology?

During a meeting, the MOBIlearn European project members contributed to the theory building about mobile learning. A list of the key findings is presented below [34]:

- **It is a learner that is mobile rather than the technology:** Learners can manipulate whatever technology they have close to them as they move between settings. For example, users own, or somebody else's mobile phones, computers, books, notepads, etc.
- **Learning is connected with other activities as part of everyday life:** It is complicated to separate the learning process from our daily activities, which can set the learning contexts. Learners can gain knowledge through conversation, reading, or watching television.
- **Learning can generate and satisfy goals:** The reasons to start learning can be external goals (like curriculum or study plan), learners' needs and problems, curiosity, or chance. From these motivations, the learner is allowed to create new objectives that he can explore through formal or informal study.
- **The control and management of learning can be distributed:** Traditional education gives authority to the teacher. However, mobile devices help distribute this responsibility through learners, guides, other teachers, technologies, and resources such as books and locations.
- **Learners construct context through interaction:** Context is key to understanding mobile learning. Instead of considering this element as static because it is not something that encloses

the learner at a given time and place, it should be viewed as a dynamic element, changing depending on the learners and their interactions between them and the environment.

- **Mobile learning tends to complement and conflict with formal education:** Learning activities can be extended outside the classroom. There are some examples, such as homework, trips, and visits. Mobile devices can contribute to collecting and analyzing information. However, they can also interfere with the stable environment of a classroom if they are allowed inside these spaces.
- **Mobile learning raises profound ethical issues of privacy and ownership:** Nowadays, people with interest can use devices to monitor some aspects of other people's life. Assuming this fact, teachers and parents access all the student's learning process details. However, this can be a problem for privacy during childhood. Nevertheless, it is well-known that technology companies already do that and allow parents to track the location of their children for safety.

2.7 Designing mobile learning

It is well-known that context is one of the critical elements of mobile learning, and it can change from one to another. Therefore, the main goal of designing mobile learning technology is to ease communication within and through different contexts. To achieve that goal, designers of mobile learning must understand how to develop technologies, media, and interactions to allow a smooth flow through various contexts and integrate mobile technologies to permit innovative activities inside education. According to Sharples et al. [32], in 2006, researchers like Naismith and Corlett suggested general principles based on what they learned about mobile learning:

- Interactions must be quick and straightforward;
- The content has to be flexible enough to be accessible through contexts;
- Taking into consideration the particular affordances, such as audio or user anonymity, that mobile devices possess to contribute to the learner experience;
- The objective is not only to "deliver" but facilitate the learning process. Mobile devices' tools (such as voice recognition and communication, keyboard, camera, timers, etc.) should be considered when designing a learning experience.

Another pertinent idea that designers should recognize is that using mobile devices is not the target but a way to enhance learning activities. The target is to increase the benefits for learners. An essential task for developers is to create rich conversations and enhance the learner experiences without interfering with the learning process itself. It means that attention is a crucial element and also a problem. How would users' focus be allowed to change from the device to the surroundings in the smoothest way possible and avoid dangerous situations (such as the hazard of walking while gazing at the screen)? In the words of Sharples et al. [32], some authors report the advantages of using audio presentations to enhance or interpret surroundings, for instance, by telling the story behind a museum exhibit or tourist site. Sharples et al. [32] cited Reigeluth (1999), who offered a design theory with clear guidance about how to help people learn and develop. According to the theoretical foundations, mobile learning instructional design should:

- Support learners to reach individual understanding through conversation and exploration;
- Support learners' collaboration to build common knowledge;

- Use technology to enrich learners' collaborative knowledge-building with other learners and teachers;
- Support learners' transitions across learning contexts.

Factors to a well-succeed mobile learning project. In 2006, Naismith and Corlett [36] identified five critical factors for developing a successful mobile learning project:

1. **Access to technology:** Make sure that mobile technology is available where and when needed, allowing users to use their own devices or giving them the devices they should use at home or on the move.
2. **Ownership:** Allow the users to use their technology or give them the sensation of using the device as if it were their own. It helps to fill the gap between institutional and personal learning.
3. **Connectivity:** Ensure the users have wireless or mobile phone connectivity to access learning resources, connect with other learners through contexts, and share their materials and progress.
4. **Integration:** The learners' curriculum, experiences, or daily life are integrated with the mobile learning projects to maintain an electronic portfolio or record of learning.
5. **Institutional support:** Learners have relevant resources in mobile format, trained staff, and technical support.

2.8 Evaluation of Mobile Learning.

Generally, developing new technologies includes an evaluation part to test the system's effectiveness. Mobile learning has a complex evaluation because it is necessary to test the technology component and the education. Sharples et al. [32] identified the challenges in evaluating mobile learning and some solutions:

- **The unpredictability of the context of use:** Typically, technologies are tested assuming that the context is fixed and well-defined. However, as was explored before, in mobile learning, the context is not static, and it can vary significantly as the learner interacts with other users and places. Additionally, mobile learning contexts are difficult to observe, predict or stimulate.
- **The unpredictability of the learning process:** Mobile learning can complicate the distinction between formal and informal learning. Usually, students bring homework into the classroom for assessment or even bring items part of their exploration (such as leaves, stones, or others) to explain a lesson. However, mobile devices offer more ways to bring materials to the classroom through images, notes, and audio recordings. Sharples et al. [32] proposed the following questions: Where does school end? When can a child delight in learning for its own sake without having to present the results for school assessment?
- **The unpredictability of mode of use:** In the words of the researchers [32], the technology used for mobile learning is designed to enhance learning practice, but it can also change and affect that practice. Designers can't determine how learners will use the technology until real people test it in real settings. Sometimes the designer's idea doesn't match how people adopt that technology.
- **Looking beyond the "wow" effect:** Users' enjoyment and motivation are characteristics included in the mobile learning evaluations. Researchers cited by Sharples et al. [32] propose

that the high affective value of mobile learning is influenced by elements like control over goals, ownership, fun, communication, learning-in-context, and continuity between contexts. There are attributes of mobile devices that make learning enjoyable. Therefore, an investigation to specify which are those attributes and how to take advantage of them is necessary. As a result, when evaluating mobile learning, we should try to see beyond the first "wow" factor associated with the technology and investigate the effectiveness of mobile devices in engaging learners over the longer term.

These challenges demonstrate the difficulties in data collection, analysis, and assessment of learning results in mobile learning. Consequently, researchers are exploring new tools and methods for the collection and analysis of data, research methodologies, and approaches suitable for interpreting such data and issues in designing mobile learning research. Some examples are mobile eye tracking, co-design, and data mining of automatically generated data logs. Finally, the evaluation is a process that should be continuous, starting with the inception of a project and then following with the design, implementation, deployment, and beyond.

In this dissertation, the aforementioned key aspects of mobile learning will be used to design and evaluate an AR mobile application where the wider audience learns about the curiosities and concerns of NARWs. Knowing this information, it is expected that users of the recent interaction created for this dissertation will use it to learn more about the species in a public context. The participants will be evaluated through their mobile devices to test their knowledge about NARWs, giving them the opportunity of having anonymity.

3 Importance of North Atlantic Right Whales - NARWs

As the Introduction (Section 1) mentioned, the project's goal is to raise awareness about the NARWs. Therefore, this section is dedicated to these species and serves to gain knowledge about the characteristics, way of living, and threats, among other information.

Description. The North Atlantic Right Whale, whose scientific name is *Eubalaena glacialis*, is a whale species that live in coastal or continental shelf waters and sometimes in deep waters [9]. In the words of the Whale and Dolphin Conservation (WDC) organization, NARWs are enormous, slow-swimming, baleen whales [10]. Regardless of their heftiness, NARWs are skilled acrobats and are well-known to breach and slap their flippers and tails against the water. Other names for this species are "Tube whale," "Biscayon right whale," "Biscay whale," and "Black right whale."

Status. NARWs are "critically endangered" in the IUCN classification (Fig. 7), according to the red list assessment in 2020 [5]. Some fonts, such as World Wildlife Fund (WWF), mentioned that only 400 (approximately) currently exist. Others, such as the WDC and the National Oceanic and Atmospheric Administrations (NOAA) [11], report that the remaining exemplars are between 350 and 360. Currently, whales are protected from direct harvest, allowing partial recoveries in many previously depleted species [37]. However, the number is still below their historical abundance, and the number of mature individuals is around 200-250 [5].

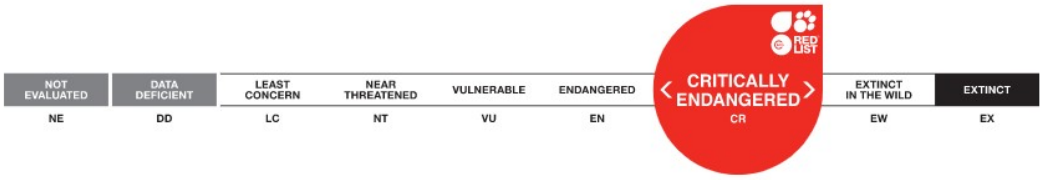


Fig. 7: NARW status reflected on the IUCN scale (retrieved from [5])

Size and Weight. According to the WWF [9], a NARW can reach 17 meters long. The WDC [10] reports that males and females could get a maximum size of 18.5 meters. However, NOAA [11] informs that they only reach 15.8 meters long. The calves' size is between 4.25 and 4.6 meters. A study about the size of NARWs [37] demonstrates that the threats they face during their lifetime are the causes of their size reduction. These threats can be incidental human impacts, such as vessel strikes and entanglement in fishing gear. Another problem is climate change, which affects prey dynamics. Fig. 8 compares the size of a NARW and a scuba diver.

Appearance. According to NOAA [11], NARW has completely black bodies, or some have irregular white patches on their bellies. They have a strong completion and don't have dorsal fins. Their blow spouts have the shape of a "V." NARW tail is large, deeply notched, and utterly black with a smooth trailing edge; their pectoral flippers are short compared with other whale species, but they still are broad and with a shape of a paddle. NARWs' heads have callosities (Fig. 9) [12]), which are white patches of rough skin. These callosities form a unique pattern for each NARW, and scientists use them to identify them.

[9] https://wwf.ca/species/north-atlantic-right-whales/
[10] https://us.whales.org/whales-dolphins/species-guide/north-atlantic-right-whale
[11] https://www.fisheries.noaa.gov/species/north-atlantic-right-whale
[12] https://photolib.noaa.gov/Collections/NOAAs-Ark/Whales/emodule/722/eitem/30405

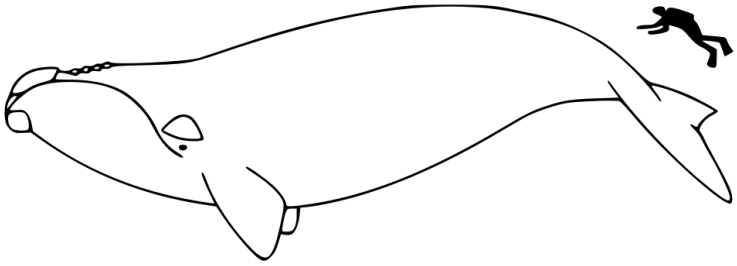


Fig. 8: NARW size compared to a scuba diver.

Fig. 9: Close up of a NARW's callosities. Photo from NOAA Photo Library.

Where do they live? NARWs are primarily in Atlantic coastal waters, but this species is known to travel far offshore, over deep water too. They migrate seasonally in small groups or alone. They can be found in New England's waters during spring, summer, and fall. They go to Canadian waters to feed and mate. Some NARWs travel from the feeding zone to the calving grounds of South Carolina, Georgia, and northeastern Florida each fall. The travel distance is around 1000 miles. NOAA Fisheries [11] designated two areas as critical habitats for this species (Fig. 10):

- Off the coast of New England as the foraging area.
- Off the southeast U.S. coast from Cape Fear, North Carolina, to below Cape Canaveral, Florida, is the calving area.

Lifespan and reproduction. At optimal conditions, a NARW can reach 70 years old. Nowadays, scientists monitor NARWs and report that their lifespan is reduced due to threats [37]. Females live to around 45 years old and males only to 65 years old [11]. Recently, some researchers have recorded an increasing number of deaths among adult females compared to their counterparts. Consequently, it is expected that there are more male than female exemplars. It causes energetic

Fig. 10: NARWs' distribution map [11].

stress from reproduction to females, especially when they are victims of entanglements or vessel strikes [37]. Regarding reproduction, females are sexually mature at about age 10, and their pregnancy lasts around a year. In normal conditions, a female can get pregnant every three years, but with the aforementioned threats, this cycle now takes 6 to 10 years due to the stress of NARWs. In Fig. 11, it is possible to observe two different photographs of NARWs with their calves. These photographs are from NOAA Photo Library [12] and the Georgia Department of Natural Resources [13].

(a) Photography is from NOAA Photo Library [12]

(b) Photography from Georgia Department of Natural Resources [13]

Fig. 11: Photographies showing two NARWs with their calves.

Threats. In this section, some of the threats are mentioned. However, in this subsection, these threats are approached with more information because it is relevant to the project goals.

Entanglements: One of the most problematic threats is entanglement. According to NOAA, around 85% of NARWs are entangled in equipment for catching fish at least once during their

[13] `https://georgiawildlife.com/conservation/rightwhales`

lifetime. These accidents can produce serious injuries to a whale's body, even deep cuts that infections and mortality can follow. In a recent study about mortality in entanglements [38], using an abundance estimation model to derive estimates of cryptic[14] mortality of NARWs, researchers found that observed carcasses accounted for only 36% of all estimated death during 1990-2017. However, it is essential to mention that they also found that 49% of the deaths determined the entanglement as the cause of death during an autopsy, and the number of cryptic deaths suffering severe injuries related to trap was around 87%. Other consequences of the entanglement are stress, weakness, hunger, and lack of energy to swim because they spend it trying to escape the fishing gear. This is the prominent reason females have fewer calves, and the size of NARWs, generally, is reducing [37]. The Nature Conservancy [15] published in their newsroom about the NARW's fight for survival and included a picture (Fig. 12) with a whale with signals of being entangled.

Fig. 12: This picture is of a female NARW with her calf. Notice that this whale still has vestiges of being entangled before. (Photography from Georgia Wildlife Resources, and seen in The Nature Conservancy webpage [15]).

Impact Collisions. Another major threat to NARW is the collision with vessels. The major ports along the Atlantic Ocean are close to their habitats and migration routes, increasing the probability of this species being hit by a ship. The injuries produced by these situations are serious, from cuts and broken bones to internal injuries that can cause death (Fig. 13). The danger is not in the size of the vessel but in the navigation speed. The faster the ship travels, the higher the probability of injuring or killing a whale if this collides with one [11]. This is demonstrated by research [12] where findings revealed that fatal vessel strikes started being reported in the 1800s when the ships began to reach between 13 kn (24 km/h approximately) and 15 kn (28 km/h around). Another critical period was between the 1950s-1970s, when the speed increased even more. Currently, organizations and conservationists are making efforts to implement a regulation on vessel speed [16].

[14] According to Pace III et al. [38], in fisheries management literature, postrelease mortality of fish has been termed "cryptic mortality," and this term has been applied to human activities that kill marine mammals without resulting in an observed carcass.

[15] `https://www.nature.org/en-us/newsroom/florida-north-atlantic-right-whales-fight-for-survival/`

[16] `https://www.fisheries.noaa.gov/feature-story/rule-amend-north-atlantic-right-whale-vessel-speed-regulations-open-comment`

Fig. 13: A calf with deep wounds product of a vessel strike. Unfortunately, the calf died on the coast of Florida. (Photography from NOAA Fisheries [16])

Climate change. The oceanographic changes in the Northwest Atlantic ocean due to climate change are part of the main factors contributing to reduced reproduction and higher vulnerability to human-caused threats [11]. During the last ten years, NARWs altered their distribution patterns due to changes in prey location and availability due to the high temperatures of oceans. Climate change is related to other threats because of the changes in their feeding zones. The NARWs are moving to zones where they're less protected from vessels to find food and, consequently, they're more likely to be hit by a ship or even entangled in fishing gears. This threat and its consequences are related to the population reduction of this species [39].

Noise Pollution. Besides the risk of colliding with vessels, these are related to human activities such as shipping, boating, construction, and energy exploration. These activities cause enough noise to interrupt communication and the expected behavior of NARWs [11]. Noise pollution interferes with the NARW biology [11] reducing their ability to detect and avoid predators and human threats, navigate, identify obstacles, find food and mates [11].

Health conditions. Researchers used photogrammetry from remote aerial vehicles and conducted the largest population assessment of right whale body conditions. As mentioned in the problematization (Section 1.1), NARWs have poorer health compared to other similar subspecies, the Southern Right Whales (*E. australis*) [6]. This type of right whale is found near the coasts of Argentina, Australia, and New Zealand (Fig. 14). The poor body conditions of the NARWs are the result of the threats mentioned before. Christiansen et al. found that NARW juveniles, adults, and lactating females have lower body condition scores than the SRW populations [6]. NARW and SRW differences could result from genetic isolation and environmental conditions adaptations. Researchers describe the suppressing growth, survival, age of sexual maturation, and calving rates as the causes of their unhealthy conditions.

NARW contribution to marine ecosystems. NARWs and other whale species, in general, are great contributors to the environment. Great whales have high metabolic demands, and it probably has a strong influence on the ecosystems. They are consumers of invertebrates and reservoirs of vertical and horizontal vectors for nutrients. Whales are also detrital sources of energy and habitat in the deep sea [40].

Fig. 14: Comparison between the body health of the right whale species. The three on the left correspond to *E. australis* from Argentina, Australia, and New Zealand. The one at the right corresponds to *E. glacialis* (NARW). Rertieved from [6]

Whale pump. One of the most essential cycles in the ecosystems has, as participants, the whales. This process is known as "whale pump"(Fig. 15) [7]. Microbes, zooplankton, and fish are the fonts of recycled nitrogen in coastal waters. However, great marine mammals can contribute to that process by enhancing primary productivity in their feeding areas. Whales and other mammals concentrate nitrogen near the surface by releasing flocculent fecal plumes. Despite of current reduced population, marine mammals such as NARWs provide a vital ecosystem contribution by maintaining productivity in regions where this process materializes in high densities [7].

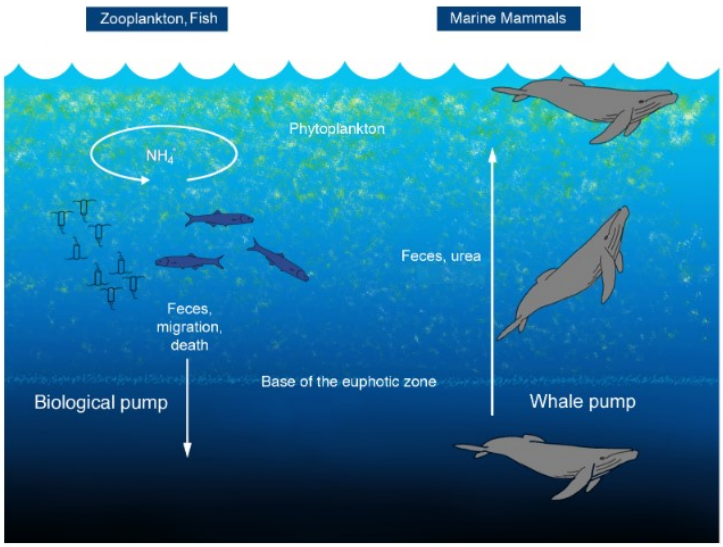


Fig. 15: A conceptual model of the whale pump (retrieved from [7])

NARW in Madeira Island. The only documented report of this species in Madeira Island was on February 27th, 1967 [41]. On this date, a Madeiran whaling company captured a female NARW with her calve.

Whaling industry in Madeira. In Madeira, the whaling industry started in the early 1940s. Sperm whales (*Physeter macrocephalus*) were the main species to be hunted. The Whaling Company of the Madeira Archipelago (Empresa Baleeira do Arquipélago da Madeira – EBAM) was founded in 1944. At the end of the 1940s, a factory which products from the mortal remains of animals was built (Fig. 16a). These products were oil from fat and bones, used for lubrication of industrial machinery and chemical industry, and as a substitution for mineral fuels during World War II when Madeira was scarce (Fig. 16c and 16d). Other products were protein for feeding cattle and fertilizers (Fig. 16b). This factory was in Caniçal city.

(a) Aerial photography of the EBAM factory.

(b) EBAM brand on a plastic sack for packing whale flour.

(c) EBAM brand for marking oil barrels.

(d) A sample of whale oil produced by EBAM factory.

Fig. 16: Photographies related to the whaling industry in Madeira Island from the *Museu da Baleia*'s website [17].

A movement for the defense of whales began during the 1970s. Their operations consisted of rejecting the sale of products derived from these animals. The reaction from this movement and the reduced number of sightings motivated the whaling industry's voluntary cessation in Madeira in 1981, and in 1986 government created a law to declare the waters around the island as a sanctuary for marine mammals. This summary of the story of the whaling industry is from the Madeiran *Whale Museum* website [17].

The aforementioned NARW characteristics will be used to portray the curiosities, opportunities, and threats to the wider audience, using the AR application with a mobile learning approach. The specific selected themes to present in the application are the reduced size (around 15m) of the NARW to raise awareness about the threats' consequences as a curiosity; the number of

[17] `https://www.museudabaleia.org/en/o-museu/whaling-history.html`

entangled whales (around 80%) during their lifetime as one of the threats that these creatures face currently; and the whale pump cycle as a contribution to the marine environments, reinforcing their importance as an opportunity to reduce the climate change impacts. The following section will explain the process behind the project.

4 Methodology

This section explains the design, development and adaptation process of the existing ARDome app[18], designing the new modality of interaction using AR with the NARWs. The studies related to the app are also described.

4.1 App Design

This subsection describes all the processes of the new interaction implementation and the necessary updates for the ARDome app, including the creative process and the software used.

Analysis and Brainstorming. Before beginning the development part, there was a process that involved a field study (Section 4.3), an investigation of the NARW (Section 3), and brainstorms to define how the application should look, how the application will pass the information to the users, leveraging the existing geodesic structure as a tool to inspire the users to interact with it using the app. In this part, the creative process behind the project.

First ideas. The project started with the proposal of creating a new interaction for the ARDome app, providing the modality with the NARW interaction. This app started a year before with the development of an interactive experience whose protagonist was a Caretta-Caretta turtle. It has an AR game whose goal is to collect underwater trash. A colleague from Design of Interactive Media at the University of Madeira[19], and the author of this dissertation conducted a user study about this first interaction (Section 4.3), observing the people how they interact with the first app modality. Many ideas came during brainstorms about the future NARW mode, from which were the following:

1. A simulator where the user has the role of a NARW and has to avoid the vessels traveling at different speeds.
2. Augmented Images to trigger storytelling interactions with a narrative about the life of a NARW.
3. Augmented Images using infographics with interesting and shocking pictures without text and using short quizzes to test the knowledge and interpretation.

The evolution of the ideas is noticeable. The first one was similar to the concept of Caretta-Caretta due to the gamification [20]. The second idea was a transition to the final thought, having an interactive part where the people can learn something about the NARW while it tells its story. Despite the second idea being attractive, the truth is the duration of this type of interaction may be longer than expected, and we could have the risk of having users not completing the experience. Therefore, a final idea where the goal is to inform the user quickly while creating an effect on them. Furthermore, the objective of passing the information, no matter the users' language, would be achieved using images rather than texts or audio. In other words, NARW interaction goal was to keep the simplicity while giving the information through Augmented Images and raising awareness about NARWs. On top of that, using mini interactive quizzes within the app, it is possible to observe how the audience use it when responding to the questions (Section 4.3). The next step was

[18] https://play.google.com/store/apps/details?id=com.tigerwhale.ardome

[19] Pedro Abreu, student of second year

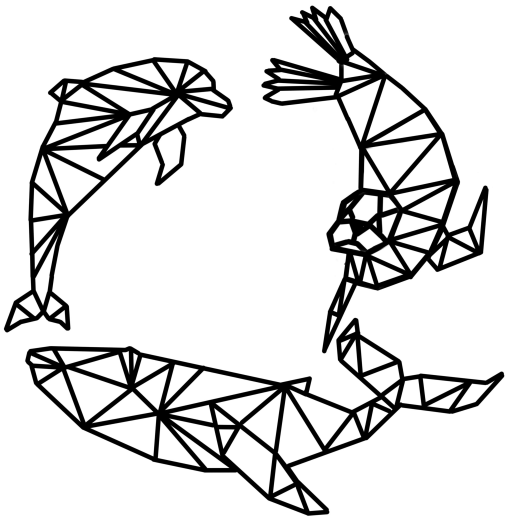
[20] **Gamification:** the process of adding games or gamelike elements to something (such as a task) to encourage participation (`https://www.merriam-webster.com/dictionary/gamification`)

choosing the topics related to the species to present to the users. Indeed, research about NARW (Section 3) offered enough data to represent. Still, we had to choose at least three, considering the capability of representing the information using exclusively a picture and the impact it should have on the user. Additionally, it was necessary to convey that information in the form of pictograms (Augmented Images) to be placed in woods on some sides of the dome and allow the user to make a lecture with the application and observe the infographics to be interpreted. Design of the pictograms and infographics followed because the Unity and ARCore engine need to evaluate the images to determine if they are adequate enough to be read by the user's device. Also, despite being in an engineering career, the author of this dissertation has been interested in design since childhood, so it was an opportunity and an honor to be part of the design process as well.

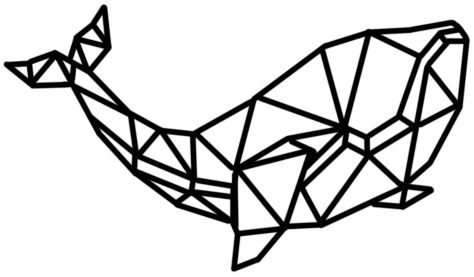
Pictograms in the wood. One of the first steps in the app development was designing the pictograms, which serve as Augmented Images, i.e., images that will execute instructions when read. There should be three pictograms, one related to information or curiosity (info), another related to a contribution, and the last to a threat. The pictograms were designed using the Sketchbook app for Android.

- **"Info" pictogram:** The initial idea for this pictogram was to give an idea of general information. Initially, a set of marine mammals was designed, including a dolphin, a seal, and a NARW (Fig. 17a), as a reference to part of the marine megafaunas that is part of the INTERAQUATICA project [16]. Indeed, this version was imprecise and could confuse the user by making it believe that the interaction is not only about the NARW but also includes other animals. Therefore, a second version was designed (Fig. 17b) with the NARW. With the support of aforementioned students from the MDMI course, second version was obtained adding a title and making minor adjustments to the pictogram (Fig. 17c). Finally, the pictogram was printed on wood with a laser-cut machine and painted (Fig. 17d).
- **"Contributions" pictogram:** The first pictogram (Fig. 18a) represented fish, seaweed, and marine ground, referring to the contribution NARW makes to the marine environment (Section 3). However, we implemented some consistency and used the second version for the "info" pictogram (Fig. 17b) to create a pattern (Fig. 18b). ARCore and Unity software scored well on this image. Still, errors occurred when we scanned the image by confusing the pictograms with the same pattern but in different positions, resulting in the presentation of many infographics at once. As expected, doing an edition by inverting the orientation of the whales (Fig. 18c) in the pictogram did not solve the problem. We noticed that we have to avoid images with the same pattern. Therefore, students modified the lines in the drawing to change the design (Fig. 18d). Finally, the image was printed on the wood (Fig. 18e).
- **"Threat" pictogram:** The first design (Fig. 19a) referred to the trash in the marine environment to reflect this problem. However, this theme was already approached by the turtle interaction (Section 4.3). Author o dissertation made a second version inspired by the multiple threats NARWs suffer (Fig. 19b). Including entanglement with the fishing nets, whaling industry, and polluted seas. A human skull in the middle reminds a pirate logo related to the seas, but it especially represents the danger behind the anthropological activities. It was the favorite pictogram of the team due to the astonishing effect that it should have on the users. However, at the end and as the same with the "contributions" pictogram, we decided to normalize to the same style, where students created a third version (Fig. 19c). As predicted, we had problems scanning the pictures using the same pattern as the "info" and "contributions" pictograms.

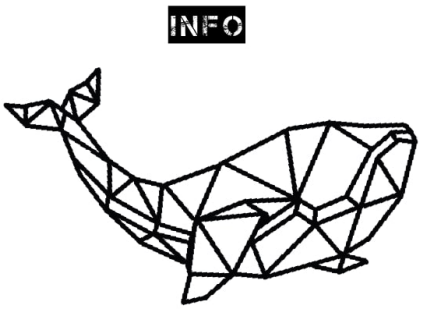
The pattern's lines were edited too, but in this case, the idea was to look like a whale in its bones (Fig. 19d). Then, it was printed on wood (Fig. 19e).



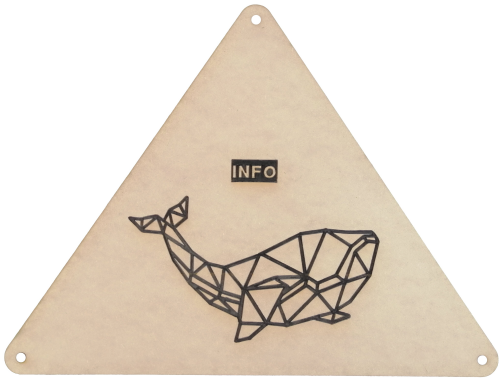
(a) First version of the pictogram (designed by Engineer Jocelyne Teles).



(b) Second version of pictogram (designed by Engineer Jocelyne Teles).



(c) Final version of the pictogram (edited by Designer Pedro Abreu).

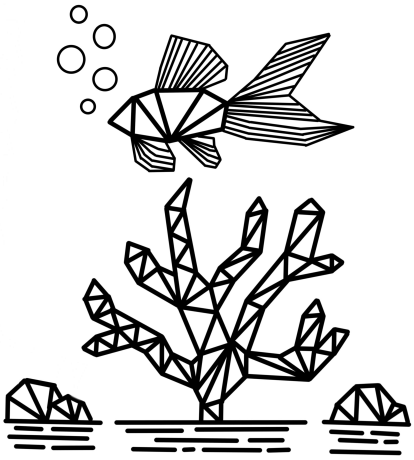


(d) Pictogram printed on the wood (painted by Designer Pedro Abreu).

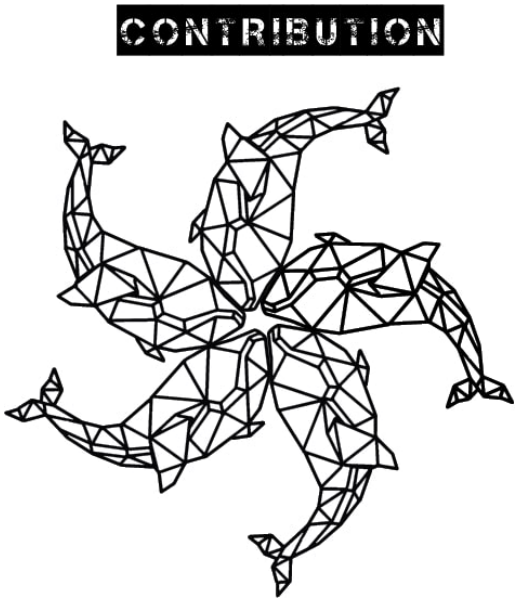
Fig. 17: Design and edition process of the "info" pictogram.

It is noticeable that the process of designing the pictograms occurred in parallel with the development component due to the dependence between the quality of the image and the scanning feature.

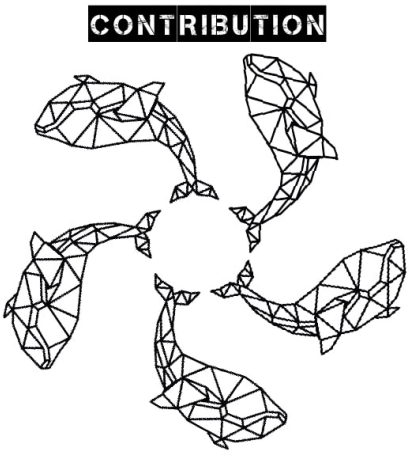
Creating Infographics. Following the motto: "One image has more value than a thousand words," infographics are typically pictures communicating complex information. In this study, infographics are used to appear when scanning the pictograms with the ARDome application.



(a) First version of the pictogram (designed by Engineer Jocelyne Teles).



(b) Second version of the pictogram (edited by Designer Pedro Abreu).

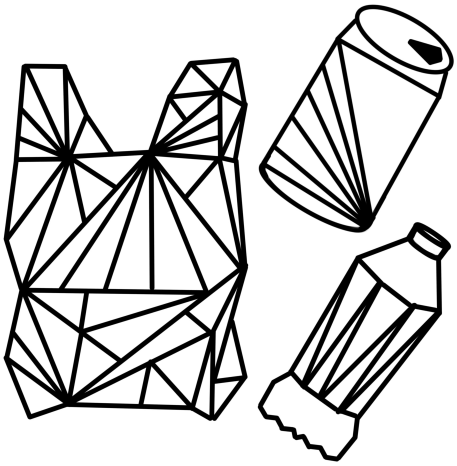


(c) Third version of the pictogram (edited by Designer Pedro Abreu).

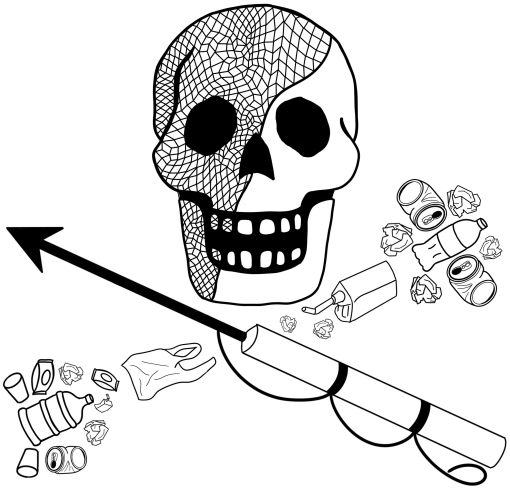
(d) Final version of the pictogram (edited by Designer Pedro Abreu).

(e) Pictogram printed on the wood (painted by Designer Pedro Abreu).

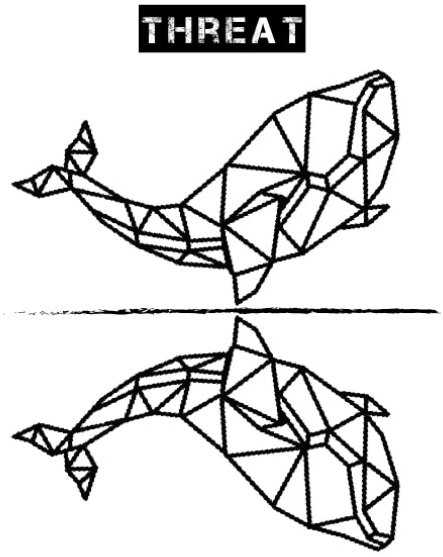
Fig. 18: Design and edition process of the "contributions" pictogram.



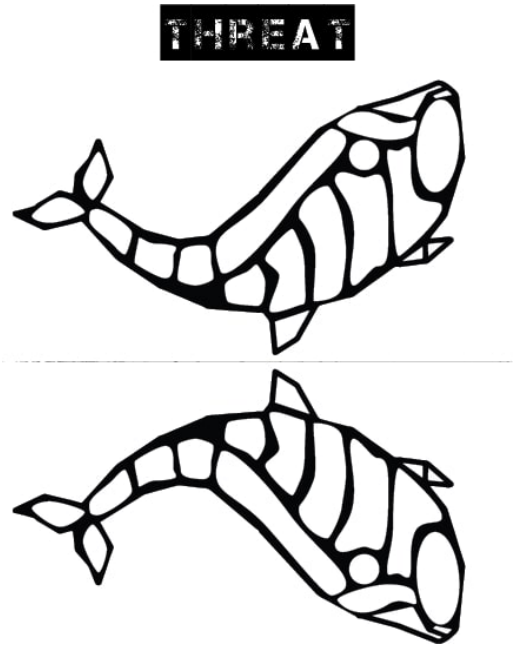
(a) First version of the pictogram (designed by Engineer Jocelyne Teles).



(b) Second version of the pictogram (designed by Engineer Jocelyne Teles).



(c) Third version of the pictogram (edited by Designer Pedro Abreu).



(d) Final version of the pictogram (edited by Designer Pedro Abreu).

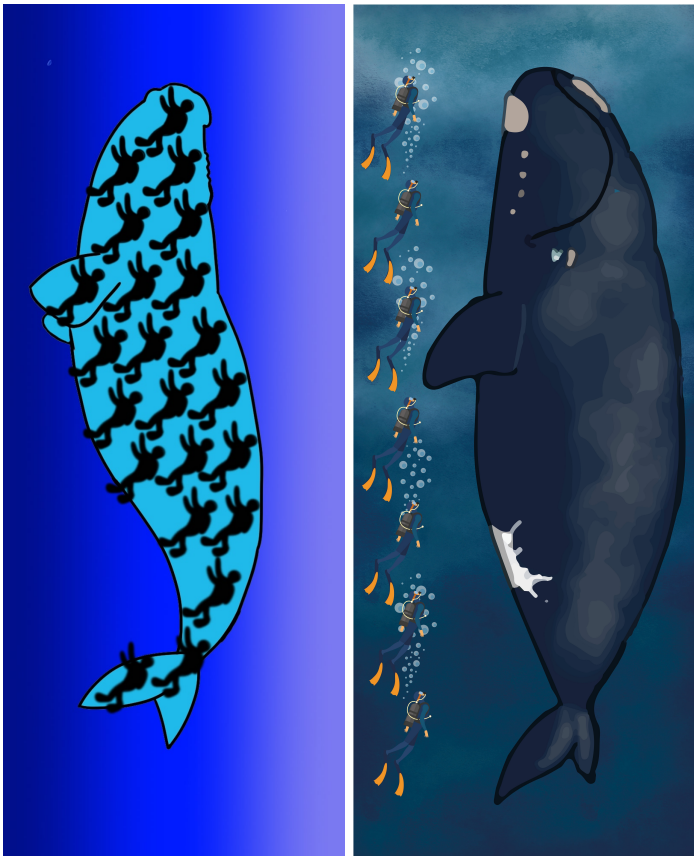
(e) Pictogram printed on the wood (painted by Designer Pedro Abreu).

Fig. 19: Design and edition process of the "threat" pictogram.

The objective is to inform the user of three facts about the NARWs without using words. Like the pictograms, author of dissertation initially designed these pictures in the Sketchbook application. Infographics were made in a different order than pictograms due to the difficulty in representing some data only with visual elements. The first infographic designed was related to threats (Fig. 20). As explained in Section 3, about 85% of NARWs are entangled at least once during their lifetime. The design of this infographic consists of transforming that percentage into the phrase "8 out of 10". Consequently, the representation of that phrase was achieved, drawing ten NARWs in total, but eight are entangled, and two are free. This image was tested in the intermediate study (Section 4.3) and passed successfully. For that reason, no modifications were needed.

Fig. 20: Infographic for the "threat" pictogram (designed by Engineer Jocelyne Teles and edited by Designer Pedro Abreu).

The second infographic is related to the "info" pictogram and has two versions. Initially, the information to be represented was how many scuba divers could "fit" in a NARW (Fig. 21a). However, the picture was a representation in 2D. It confused the audience when put to the test during the intermediate study (Section 4.3). Therefore, we changed the design representing the size of the NARW as to how many scuba divers will feet swimming alongside this whale. The chosen size was the shortest, about 15m, to represent a consequence of the threats (Section 3). Of course, for design purposes, the size was rounded to a pair number, 14m, and assumed that scuba divers could reach the 2m with flippers. Therefore, we put seven scuba divers alongside a NARW (Fig. 21b).



(a) Initial infographic (designed by Engineer Jocelyne Teles).

(b) Final infographic (designed by Engineer Jocelyne Teles and Designer Pedro Abreu).

Fig. 21: Infographics corresponding to the "info" pictogram representing the NARW size.

The third and last infographic is about the "contributions" pictogram. It was the most challenging to design. The process to be represented is called whale pump (Section 3). The first version (Fig. 22a) resulted from "summarizing" this process. However, the rule of not using text is broken in this version. Consequently, the second version (Fig. 22b) was a simplified style of the first version. This version was tested (Section 4.3) and had an inconclusive result. The design was edited once more to change the distribution and style (Fig. 22c).

(a) First version of the infographic (designed by Engineer Jocelyne Teles).

(b) Second version of the infographic (designed by Engineer Jocelyne Teles).

(c) Final version of the infographic (designed by Engineer Jocelyne Teles and Designer Pedro Abreu).

Fig. 22: Infographics corresponding to the "contributions" pictogram representing the whale pump cycle.

4.2 Software

This section describes the software and devices used to develop the new interaction for the ARDome application. Among the software are Sketchbook, Unity, and ARCore by Google.

Sketchbook. Sketchbook [21] is an app created by the Autodesk company for artists, designers, and users who want to express themselves by drawing. It's free for mobile devices – Android and iOS – but paid for desktops – Windows and macOS. The employed device was a Samsung Galaxy Tab S6 Lite, an Android tablet. I selected the Sketchbook app because it has almost the same characteristics and tools as Procreate [22], a popular app among designers, but it is exclusively for iOS.

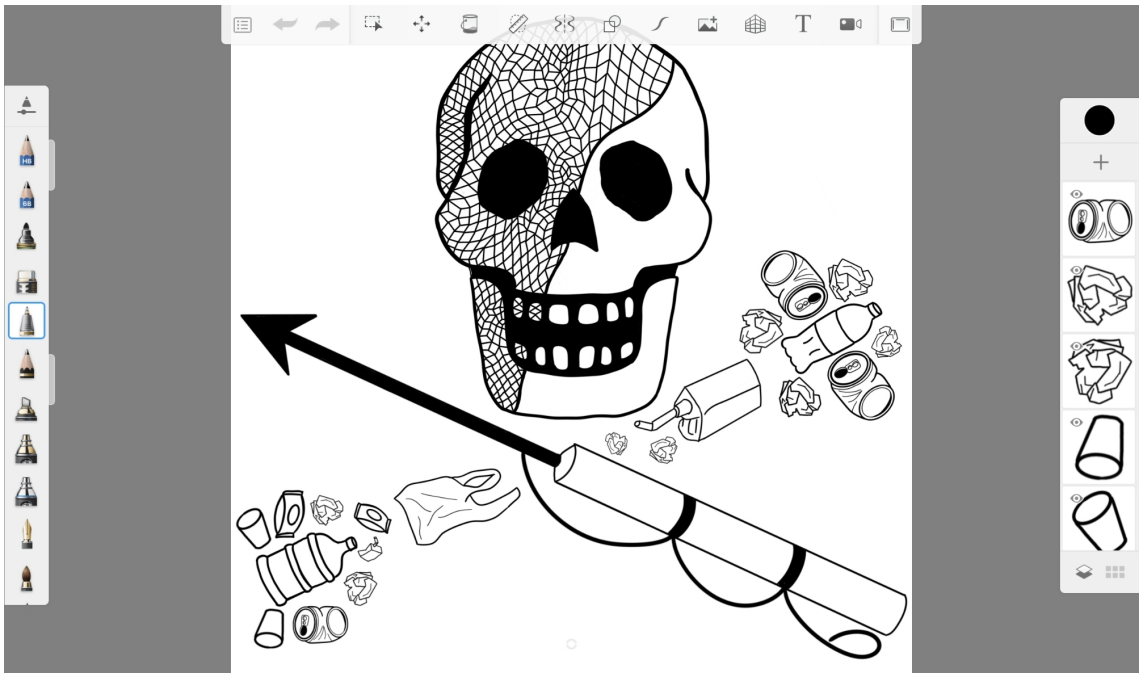


Fig. 23: Sketchbook's interface.

The tools present in the app are similar to the real-world tools that artists use to make their creations. It is possible to use various pencils, brushes, patterns, etc., which are at the left of the interface (Fig. 23). The application also has the idea of layers, which allows drawing in sections, one on top of the other. Layers are helpful when we need to edit a specific part of the drawing without affecting the others and duplicating, distorting, or changing sizes and colors. Together with the color palette, these can be found at the right of the interface (Fig. 23). On the top are multiple tools like symmetry, rules, painting, perspectives, texts, etc.

[21] https://www.sketchbook.com
[22] https://procreate.art

Unity. Unity [23] is a game engine [24] and cross-platform IDE for developers. Unity has tools that facilitate the development process, allowing to add more of them if necessary, such as ARCore. The software is intuitive, so it is used to teach and learn concepts and how to develop games. Despite of the simplicity, Unity was used to create some popular games (e.g. *Among Us*, *Pokemon Go*, etc.), and even animation films (e.g. *Adam* [25]).

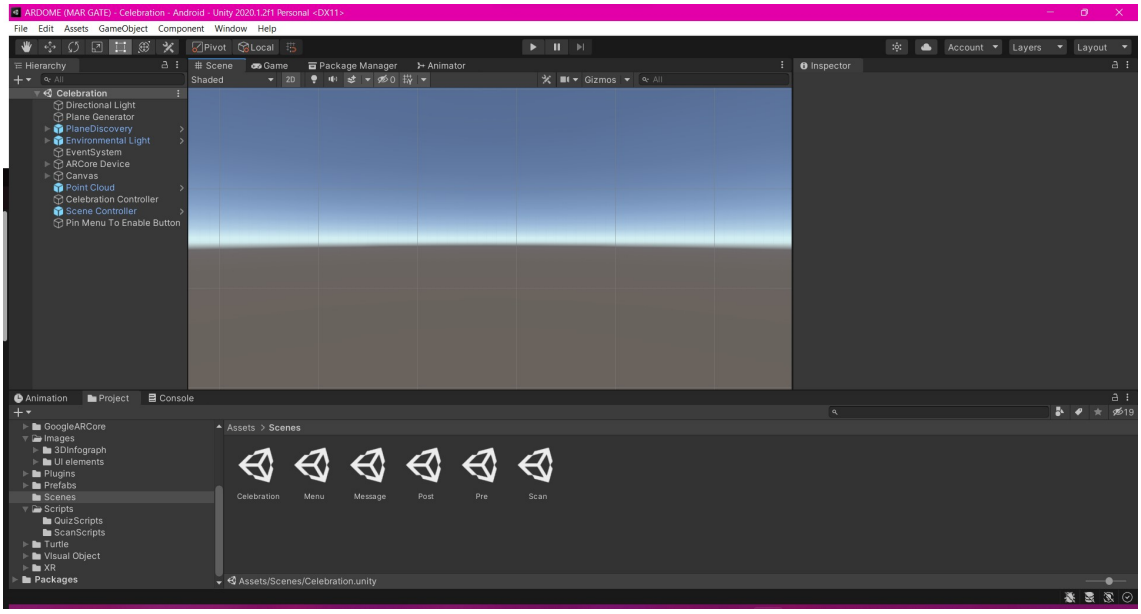


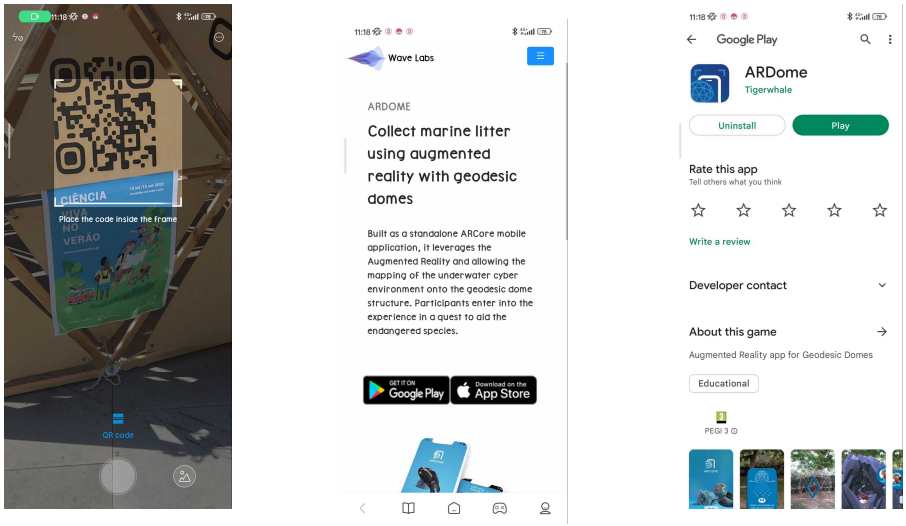
Fig. 24: Unity's interface.

ARCore by Google. ARCore [26] is a Google platform employed for the development of AR experiences. It uses different API that enables smartphones to sense their environment, understand the world and interact with information. Some examples of applications made with ARCore are *Pokemon Go* and *Jurassic World*, among others. This platform has advantages visible in the However, some disadvantages are the considerable differences between Android and iOS in terms of development, i.e., uploading the same project for both Operative Systems is impossible. Another disadvantage is the device's compatibility, especially with some Android phones. Despite some smartphones having Android OS, the architecture is incompatible with ARCore. Therefore, it is essential to consult the list of compatible devices [27] updated by Google opportunely.

Developing process. This paragraph describes developing and updating the ARDome app, focusing on the NARW interaction. Details about setup and code are in Attachment A (Section 9).

App Installation. A new feature for the app is the possibility of getting the app through QR scanning. The user can approach the dome and scan one of the QR codes printed on the dome's wood panels (Fig. 25a). This will open the Wave's website [28] (Fig. 25b), and the user, depending on the OS of the phone, can choose the app store (Fig. 25c) which will download the app.

[23] `https://unity.com`
[24] **Game engine:** A software framework designed for video game development.
[25] `https://www.youtube.com/watch?v=GXI0l3yqBrA`
[26] `https://developers.google.com/ar`
[27] `https://developers.google.com/ar/devices`
[28] `http://wave-labs.org/kits/apps/ardome`



(a) Scanning the QR code.

(b) Wave's website.

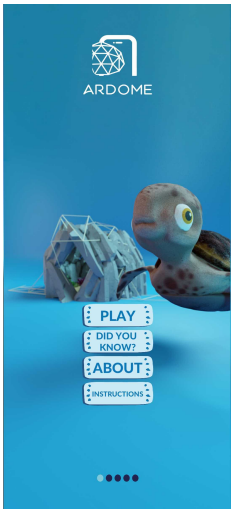
(c) ARDome in PlayStore.

Fig. 25: Process to obtain the app.

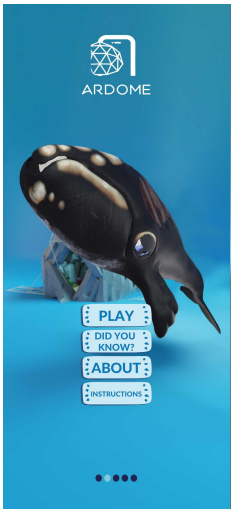
Enhancing UI Layout. The last version of ARDome included a menu where the play button opens the Caretta-Caretta interaction (Fig. 29a). With the updates, a new menu was created, including the options of playing in the Caretta-Caretta mode (Fig. 26a) or in the NARW mode (Fig. 26b) using a slider. As the NARW is the new interaction, this pass is to be in the main window, and the Caretta-Caretta turtle can be found swiping to the left. The play button on both modalities will open the respective interaction. The second button is called "Did you know?" Depending on the user's menu, it will show a curiosity about the turtle or the NARW. The novelties are in the form of infographics. The Caretta-Caretta turtle infographic (Fig. 26c) was made the last year and kept in the updated version. The NARW infographic (Fig. 26d) is inspired by the turtle's infographic and adds a piece of information about the last contribution of the whales to the marine environments (Section 3). The third button, "About," (Fig. 26e) opens a text about the project's intentions. The instructions for the interactions can be found by touching the respective button (Fig. 26f and 26g).

Interaction with NARWs. When the user touches the play button in the NARW menu (Fig. 26b), the app will open a quiz with three questions (Fig. 39) to test the knowledge about the species. The questions are received from an API [29] and the answers selected by the user are sent using the same API for analysis. The advantage of sending the questions from the API to the user is the possibility of editing questions and recycling code. The quiz appears before and after scanning the pictograms. In the beginning, test the previous knowledge or best guesses about the NARW, and at the end, check if the user learned something new through the image and interpreted the infographics well. The questions (see the Attachment D in Section 12) are related to the three main topics mentioned before when describing the pictograms:

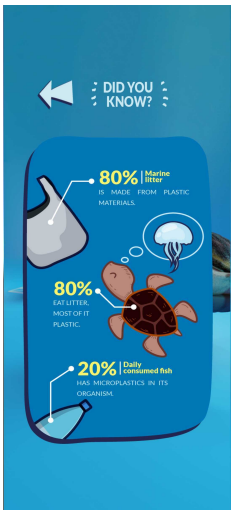
[29]The API using a database is administrated by Master Engineer Rúben Freitas using phpMyAdmin and MySQL.



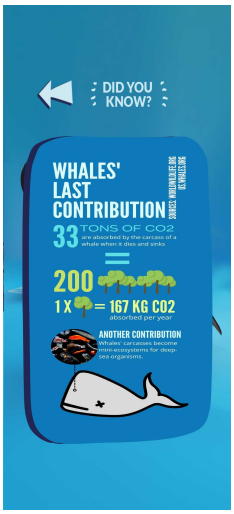
(a) Turtle menu.



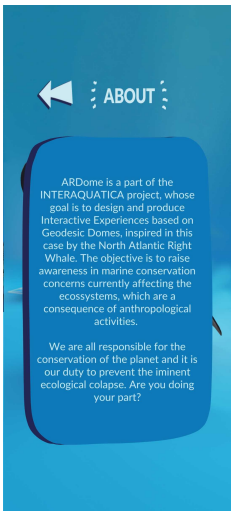
(b) NARW menu.



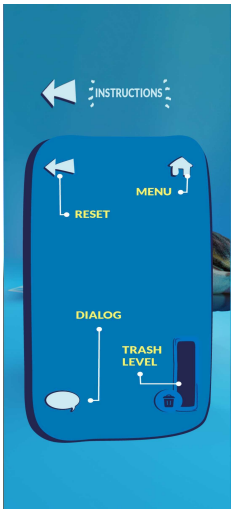
(c) Turtle's infographic.



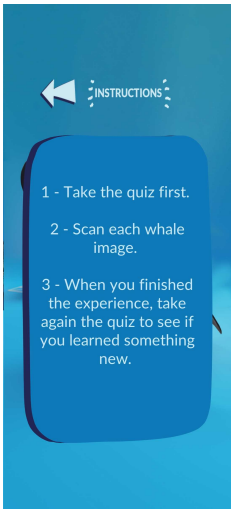
(d) Whale's infographic.



(e) Text about the project and goals.



(f) Indications for the turtle interaction.



(g) Instructions for the whale interactions.

Fig. 26: Updates including both modalities.

- The first question (Fig. 39a) is about the NARWs entanglements (Section 3), specifically, how many NARWs the user believes are entangled in fishing nets at least once in their lifetime. The possible options are in the form of estimations. The correct answer is "More than 5 out of 10".
- The second question (Fig. 39b) is related to the whale contributions (Section 3), particularly the whale pump process. The user has to make the best guess about this cycle, selecting which consumer is of what element. The correct answer is "Phytoplankton eats whale feces."
- The third question (Fig. 39c) concerns the equivalent quantity of scuba divers to the NARW's length. As explained in the part of the infographics, the adapted size is 14m, and the scuba divers will have a size of 2m (with flippers), so the correct answer is "About 7".

After the first quiz is answered, a screen with short instructions for the following part (Fig. 27a). The camera will open [30], where the user has a guide to fit the pictogram in the scanning area (Fig. 27a and 27c). When the user scans each pictogram (Fig. 17d, 18e and 19e), each corresponding infographic will appear as an augmented image (Fig. 27d, 27e, and 27f). A time counter starts when all the infographics are scanned (Fig. 27g). A message appears asking if the scan is complete or is necessary more time (Fig. 27h). A button to finish scanning will appear if more time is necessary (Fig. 27i). When the user finishes the section, a short instruction for the following section will appear (Fig. 27j). When the scan floor section is done, a 3D model of a NARW will appear (Fig. 27k).

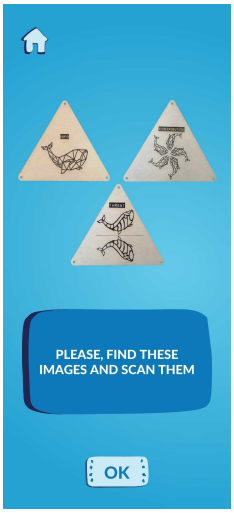
4.3 Performed Studies

This subsection exhibits the studies' methodology. These studies help understand and evaluate the application modalities when the users interact with them. Three studies were conducted:

- **Study A** - University Atrium. This one served to understand how people interact within the immersive AR setup (**RQ1**).
- **Study B** - Indoor Auditorium. This study set up infographics depicting three marine types of information. We performed an analysis to understand the level of understanding of the wider public (**RQ2**). The previous version of the quizzes' (Section 12) questions present on the app were used with the mentioned infographics.
- **Study C** - Public Square. This study encompasses the results from prior studies A and B, further encompassing the interaction with the usage of pictograms (**RQ3**). In this study, the quizzes (Section 12) were used in the app.

Study A - University Atrium Study A was conducted before the development of the whale modality, and the goal was to understand the app's effects on the users and collect their opinions using forms. A study using an AR application built in the last year took place in the atrium of the University Madeira building [31]. The study sample included 40 participants divided into two independent groups:

[30] Permissions related to the camera are when starting the application for the first time.
[31] `https://goo.gl/maps/1RqH8mxWM326knWaA`

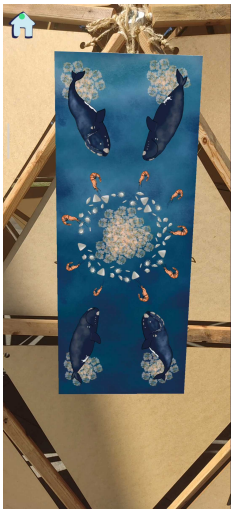


(a) Instructions for scanning section.

(b) Square delimiting the scanning zone to fit with the pictogram.

(c) Pictogram to be scanned.

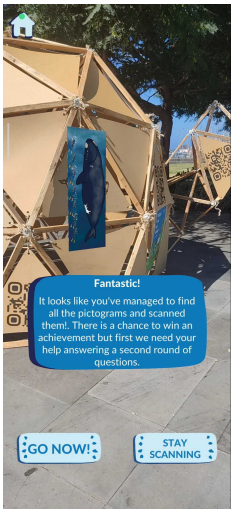
(d) "Info" infographic in AR.



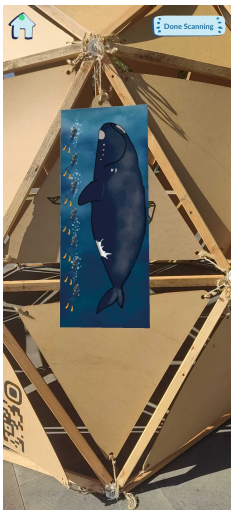
(e) "Contribution" infographic in AR.

(f) "Threat" infographic in AR.

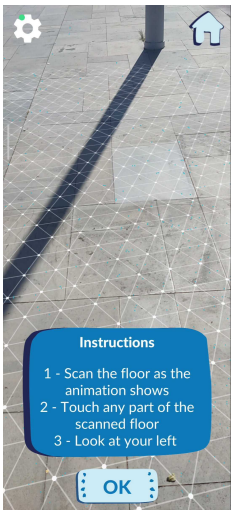
(g) All the infographics exposed.



(h) Message to conclude the scanning section.



(i) Button in the top right corner to finish scanning.



(j) Instructions to scan the floor.

(k) 3D Whale as a prize for the user for participating in the project.

Fig. 27: Scanning section of the NARW interaction (Android version).

– AR Sample ($N = 20$). The subjects used the existing ARDome [32] mobile application. AR sample was constrained to be within the provided area of $6x6$ meters on the ground (Fig. 28).

– AR Sample with shade ($N = 20$). The subjects used the mobile application in the same shade space the other study group used (Fig. 28).

Fig. 28: AR space for both experiences: with and without shade.

The participants are divided into these two groups because another main goal of the study is to analyze if the environmental conditions also influence the emotional effects of the AR application on users.

The central research hypothesis was that overall activities influence the users' emotional state: the following pre-test and post-test measure the users' experience. The form included the following questions in the pre-study:

– **Q1.** Country of origin.

– **Q2.** Age.

– **Q3.** Gender.

– **Q4.** Emotional state (before the experience).

[32] `https://play.google.com/store/apps/details?id=com.tigerwhale.ardome`

In general, these pre-study questions are for characterizing the participants. Notice that the form collects the initial emotional state when participating in the study.

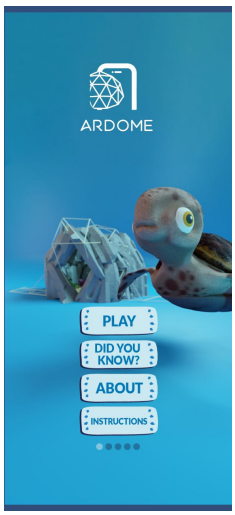
Only in the post-study form asked additional questions:

- **Q1.** Emotional state (after the experience).
- **Q2.** Indicate on the following scale how immersive the experience was for you.
- **Q3.** Indicate how much time you think you spent interacting with the application.
- **Q4.** Indicate on the following scale how much you felt absorbed by the environment.

These post-study questions compare the emotional state after using the AR application. The questions about immersion, absorption, and perception of time analyze whether these elements relate to the emotional effects.

These forms were in Portuguese as it is shown in Attachment B in Section 9. However, for some foreign participants, the questions and options were translated verbally by the team.

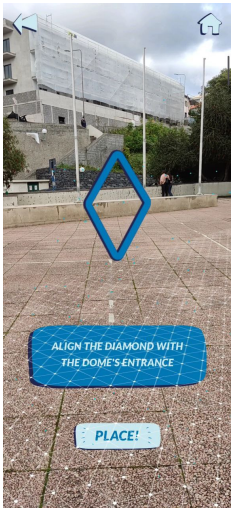
The subjects read the questions and made the answers on a paper sheet. The scales used were from 1 to 5, except for the Q3 post-study because it is related to time ($< 5min$, $5min$, $10min$, $15min$, $20min$, and $> 20min$). The participants used the mobile app's previous version. The mobile app includes a menu where the user has many options. One of them is to start the game (Fig. 29a). The mobile app starts asking users to position them in the footsteps mark. Next, the app requests users to create a virtual network of points on the ground to calibrate the ground position relative to the camera (Fig. 29b). After indicating that the floor is already marked (Fig. 29c), a diamond will appear that represents the frame of the entrance to the underwater cave (Fig. 29d), i.e., to the gameplay area for collecting marine litter and saving the turtle. The users will have to align this diamond with the open space area. After accepting that the diamond is aligned (Fig. 29f), the underwater cave will appear with the turtle (Fig. 29e), Caretta-Caretta, trapped by the anthropogenic-made litter thrown into its environment. Caretta-Caretta will ask the user to help clean their home from it, thus eliminating this marine litter. When the users enter (Fig. 29g) the underwater cave, the game will begin (Fig. 29h). The mission is to collect ten items (glasses, bottles, plastic bags, and scissors). The users must point the camera toward the litter to collect them by tapping the item on the screen. Once the users pick all the things (counted in a bar), as shown in Fig. 29i, the app will invite them to leave the cave (Fig. 29j). Outside, the user will encounter Caretta-Caretta, happy and liberated (Fig. 29k), where she will appreciate the user's gesture and leave. The user can see how she moves away freely (Fig. 29l).



(a) App menu.

(b) Instructions for the net.

(c) Floor filled with the net.



(d) Align diamond.

(e) Caretta-Caretta asking for help.

(f) Close cave view.

(g) Open cave view.

(h) Garbage to collect.

(i) Counting points

(j) Finished game.

(k) Caretta-Caretta happy and free.

(l) Caretta-Caretta is free to go.

Fig. 29: Screenshots from the turtle interaction used in the Study A.

Study B - Indoor Auditorium. This study was conducted when the NARW modality was in the development process. The intermediate study was a short test where in Tecnopolo's auditorium [33], in an event called "MARE-Madeira Lab Meeting" [34] with 23 people (including marine biologists), the infographics were shown to confirm if the images could be interpreted correctly. We simulate a similar interaction flow of the NARW modality using a projector. The steps are in the following list:

1. First, we asked, using slides as visual support, a question related to one of the infographics with the respective options. We count the people who raised their hands each time we mentioned an option.

2. Next, we show the corresponding infographic. These infographics are in Figures 20, 21a, and 22b.

3. Finally, we show the question again and ask the people to raise their hands when we mention the option to count them. After that, we showed which was the correct answer for the question.

   The questions and options were the following:

– **Q1:** How many NARWs are caught by the fishing net at least once in their lifetime? (*Options: (A) 1 out of 10; (B) 3 out of 10; (C) 5 out of 10; (D) More out of 10.*);

– **Q2:** Who eats whom? (*Options: (A) Phytoplankton eats Zooplankton; (B) Zooplankton eats whale feces; (C) Phytoplankton eats whale feces; (D) Whale eats Phytoplankton.*);

– **Q3:** How many scuba divers would fit inside a NARW? (*Options: (A) About 20; (B) About 10; (C) About 50; (D) More than 50.*).

The correct answers were: **Q1:** *(D)*; **Q2:** *(C)*; **Q3:** *(A)*.

Study C - Public Square. We did Study C after the development of the NARW was finished and uploaded to the app store of both Operative Systems: Android and iOS. The dome was assembled in Praça do Povo, Funchal [35] (Fig. 30). This point normally has an important flow of people, and it's commonly frequent by tourists due to being near the Catamaran ports. We had permission to be in that space for four days, thanks to the Ciência Viva [36] event on Madeira Island. However, the first two days were necessary to build and modify the dome and the app considering the structure's security. The plan at the beginning was to include an entrance to the dome so the users could be immersed in the closed environment offered by the structure. Nevertheless, we considered this could be unsafe for the installation at night when nobody is there watching the dome. For that reason, we invert the orientation of the pictogram, making them look like the exterior this time. The instructions in the app suffered minor modifications, making it clear that the user doesn't need to enter, only find the pictograms in the structure's exterior.

[33] `https://goo.gl/maps/pK3gRxbRvqXDKEHb7`
[34] **MARE:** Centro de Ciências do Mar e do Ambiente. (`https://mare-madeira.pt`).
[35] `https://goo.gl/maps/Qd3ffAfJuKCYBNXK9`
[36] `https://www.cienciaviva.pt`

Fig. 30: A view of the dome in Praça do Povo with the port behind.

After mounting and modifying the dome and the app, we started the study. The condition was not to convince the people to approach the dome. The structure must attract them and use the app if they wish (Fig. 31). I collected some opinions and impressions. These are in the results section (Section 5).

(a) Users in front of the dome. (b) Person reading QR.

Fig. 31: Users interacting with the dome.

5 Results

In this section, the results are depicted encompassing three study setups.

5.1 Study A - University Atrium

Here, the forms obtained results from the studies with the existing ARDome app [37] made during these months and analyzed what we need to reach with the project. To remind briefly and to assign a short name to each sample group:

- **AR** – The sample used the app without the dome structure;
- **ARS** (AR Shade) – The sample that used the app without the dome structure and with shade.

Demographics. Most of participants in the **AR** sample were Portuguese. Other nationalities were Venezuelan, South African, Spanish, Mexican, and German. In the **ARS** sample, 95% were Portuguese, and the remained participants were Venezuelan. The exact number of participants by nationality is presented in Attachment C (Section 11). 67.5% of the participants were male, and the other 32.5% were female. The participants' ages ranged from 17 to 43 years (M = 24.55, SD = 6.89). The following bar graph (Fig. 32) represents the number of participants in each sample based on gender:

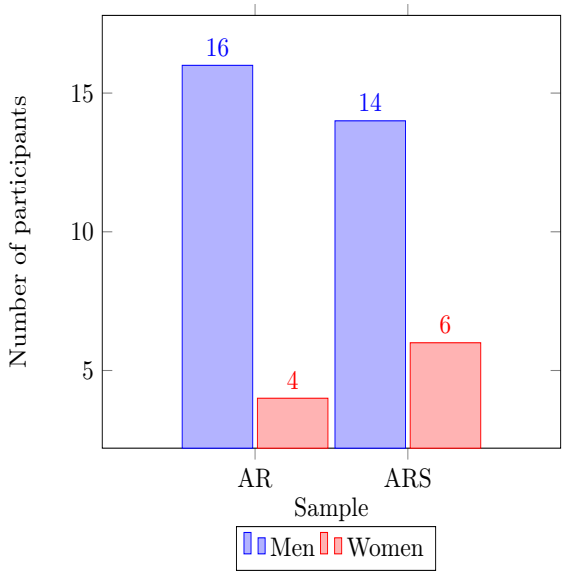


Fig. 32: Quantity of participants in classified by gender.

Emotional State Rating. The study's participants expressed their emotional state before entering the experience and after finishing it. The users answered the questions using a scale from 1 to 5 (where one means that the participant was feeling bad, and five means that the participant was feeling excellent). In each group, the values at pre-study and post-study are compared in Table 1 [38]:

[37] `https://play.google.com/store/apps/details?id=com.tigerwhale.ardome`

[38] Pearson's correlation measures the strength of a linear association between two variables. Consequently, in this study, Pearson's correlation measures these results to confirm the significance of the comparisons. However, after the dissertation's reviews, the conclusion was that these samples were small. Therefore this procedure may not be necessary because Pearson's correlation is for more extensive representative study groups.

	AR		ARS	
	Pre	**Post**	**Pre**	**Post**
Mean	3.95	4.4	4.05	4.5
Variance	.26	.25	.79	.26
Pearson's correlation	.49		.17	
P-Value	$<.05$		$<.05$	

Table 1: Table comparing results of pre-study and post-study in terms of emotions for the two groups.

A comparison between the groups in terms of emotions that the participants reported after the experience (post-study) is presented in Table 2 [38]:

	AR	**ARS**
Mean	4.4	4.5
Variance	.25	.26
Pearson's correlation	-.20	
P-Value	$>.05$	

Table 2: Table comparing post-study results in emotions for the two groups.

Immersion State Rating. In the post-study, a question about how immersive the app seemed to the participants. The question used a scale from 1 to 5 (one for not very immersive and five for very immersive). Table 3 [38] compared the values obtained in both groups:

	AR	**ARS**
Mean	4.2	4.25
Variance	.38	.41
Pearson's correlation	.27	
P-Value	$>.05$	

Table 3: Table comparing post-study results in terms of immersion for the two groups.

Absorption State Rating. At the post-study, the users responded to how absorbed in the ambiance they felt. We gave a scale from 1 to 5, like in the other cases. Table 4 [38] also compared the values obtained in this question between the groups:

	AR	**ARS**
Mean	4.16	4.21
Variance	.70	.51
Pearson's correlation	.22	
P-Value	$>.05$	

Table 4: Table comparing post-study results in absorption for the two groups.

Time perception. A question asked the time they believed they were last in the experience. The objective is to analyze the time perception of the users with the app. In the survey, we specified the time as < 5 minutes, 5 minutes, 10 minutes, 15 minutes, 20 minutes, and > 20 minutes. To facilitate the statistics, we translate these values into 1, 2, 3, 4, 5, and 6, respectively. Table 5 [38] also compared the time perception between the groups:

	AR	**ARS**
Mean	2.45	2.2
Variance	.47	.59
Pearson's correlation	.12	
P-Value	$>$.05	

Table 5: Table comparing results of post-study in terms of time perception for the two groups.

Field Observations and Comments. In this experience, some users who had to walk to the cave stopped at the entrance because they believed players could play the game there. We invited them to enter the square marked on the floor to play the game correctly. Some people experience difficulties seeing the screen under the sun.

ARS field observations. Two of the participants of this sample showed interest in future testing with a mixed reality version of the game. One participant noticed a slight delay in the app. This unique report made us assume the device was running the game having a limited capacity.

Participants' comments. The following is a recompilation of the comments given by the participants in the three samples:

- Some iOS users that participate with provided Android devices commented, *"You should consider iOS users. We wish to have the app on our phones and interact with it".*
- We have this type of comment in two opportunities: *"You should make this project a tourist attraction.*
- *"You should do activities with schools. Kids will love the interaction and will learn about these subjects."*
- Another participant said *"The positive thing about doing without structure is that I know I can play again in my house."*
- A participant suggested: *"I suggest the possibility of using this app on a tablet."*
- Another suggested, *"It will be interesting to make this with a competition table like a social game."*

5.2 Study B - Indoor Auditorium

The results of Study B are presented in Table 6.

	PRE				POST			
Questions/Options	**(A)**	**(B)**	**(C)**	**(D)**	**(A)**	**(B)**	**(C)**	**(D)**
Q1	3	14	2	4	0	3	0	20
Q2	0	7	14	8	0	6	15	9
Q3	3	4	11	7	7	0	1	1

Table 6: Results of the study. Questions and possible options are in the methodology section.

5.3 Study C - Public Square

The following tables reveal the results obtained from participants who did the complete interaction (Table 7) and participants who only answered the first quiz (Table 8).

Observing Table 7, it is noticeable that approximately 20.51% of answers obtained at the pre-quiz were correct, but the database did not receive 23.08% of the responses due to errors. At post-quiz, we got satisfactory results with approximately 74.36% correct answers; in this case, the database received all the answers. Specifying more users' performance in the quizzes, we can analyze it by each question:

- **Q1:** At the pre-test, 15.38% of the users answered correctly, while 100% of the users were correct at the post-test.
- **Q2:** In this question, 23.08% of participants selected the correct option in the pre-test. Then, this number rises to 46.15% in the post-test.
- **Q3:** 23.08% of participants were correct in this question in the pre-test, and this number increased to 76.92%.

	PRE			POST		
User ID	**Q1**	**Q2**	**Q3**	**Q1**	**Q2**	**Q3**
1	C	C	A	D	C	A
2	A	D	NULL	D	C	B
3	A	D	A	D	C	A
4	A	C	NULL	D	C	A
5	C	D	C	D	C	A
6	B	A	D	D	B	A
7	NULL	NULL	NULL	D	D	C
8	A	A	D	D	D	A
9	B	D	C	D	A	B
10	A	C	NULL	D	C	A
11	D	A	A	D	A	A
12	D	D	B	D	D	A
13	NULL	NULL	NULL	D	D	A

Table 7: Results were obtained with the ARDome application about the NARW. "NULL" is for responses that weren't sent to the database. Green letters are correct responses.

In Table 8 are the responses of people who participated but only answering to the first quiz; 33.33% of the answers were correct, and 14.29% suffered errors, in general. Focusing on each question's answers sent by this particular group, **Q1** and **Q2** obtained approximately 14.29% correct answers, and **Q3** got 71.42%. These results are normalized to make them understandable. Each user is differentiated by the Unique User Identifier (UUID), which, as the name mentioned, is unique to each smartphone. This type of data does not compromise private data and is only used to differentiate users. Therefore, we can differentiate the users. However, UUIDs are long strings with aleatory numbers and letters, and for that reason, in these tables, they are normalized using increasing numbers.

User ID	**Q1**	**Q2**	**Q3**
14	A	A	A
15	A	B	C
16	A	A	A
17	A	A	A
18	NULL	NULL	NULL
19	D	C	A
20	A	A	A

Table 8: Responses of users who only did the quiz before scanning but didn't answer it again. "NULL" is an error in receiving data. Green letters correspond to correct answers.

Field Observations and Comments On the third day of the experience, we had the honor of being interviewed by the RTP Madeira to promote Ciência Viva's events. The next day, a family came and used the application due to this report and praised the project's idea. There were moments when we kept our distance from the dome to give enough freedom to the public to approach the structure without feeling like we observed them. We studied people's reactions (Fig. 31). Some foreigners and older adults felt attracted to the dome structure but did not use the app because they did not possess a smartphone or weren't willing to use it. The decision to keep distance combined with the schedules about the event spread on social media could confuse some people. Consequently, we received a call from a family to ask for a person in charge of the project. We approached this family in this case to help. However, the child had the intuition to use the application without problems.

6 Discussion

In below, three studies results are addressed and discussed, outlining the lessons learned and rooms for improvement when testing the AR application with the general audience.

6.1 Study A - University Atrium

About emotional state. Comparing AR sample experience moments, the mean increased from the pre-experience to the post-experience. This result indicates that, in general, the users felt better when they finished the game. The data spread was insignificant as the variances at pre-experience and post-experience were low. Pearson's correlation indicated a moderate correlation between the values, and the *p-value* shows statistical significance. The **ARS** sample also registered an increasing mean from pre-experience to post-experience. The data obtained in the pre-study was more spread than that acquired in the post-study. The correlation was low, indicating Pearson's correlation value, but it was statistically significant, as the p-value showed. In comparing the results at post-experience, it is found that the emotional effects of the **AR** were slightly higher than the **ARS** outcomes. The variance in both cases is proximate and low, so the data is not very spread. Pearson's correlation value indicates a low degree of correlation; in this case, the results are not statistically significant. The importance of these results is that the app was capable of improving the users' emotional state after they did the experience. This outcome is desirable for the study, and it's something that the next project needs to repeat.

About immersion. Comparing **AR** with **ARS**, the means are very close to each other, also in the variance case. The data has a low degree of correlation and is not significant in terms of statistics. As the values were proximate from one group to another, it is possible to conclude that being in a shaded space or not, we expect that the results won't be so different. Although some participants describe difficulty seeing the screen under the sun, maybe the experience was not affected, but this depends on the player's time to play.

About absorption. The values in this question were also close, as confirmed by the means obtained in the two groups. The variance was more significant in the **AR** group. The correlation indicated by Pearson's correlation value was low, and the results are insignificant. The ambiance of the game had excellent validation from the participants.

About time perception. The time perception was similar for both groups; it indicates that the participants generally felt that they lasted between 5 and 10 minutes playing. The variance means more spread data in the **ARS** group, and the results are not significant as the last comparisons between groups. As we did not use the clock for the experience, we remain uncertain how much the participants' experience lasted during the game. By understanding the time perception and the real-time period, it is possible to understand if the players are focused enough to lose the time perception or not. For the participants, having fun or being too focused on a specific task, "time flies" during the experience [42].

6.2 Study B - Indoor Auditorium

Q1 - How many NRW are caught by fishing net at least once in their lifetime? Three people went for Option A (1 out of 10), 14 for Option B (3 out of 10), and 2 for Option C (5 out of 10). Only four were correct in selecting Option D (More than 5 out of 10). We can interpret

that most people believe there is a problem with the entanglements of this species, but maybe they don't believe the numbers should be high. The results changed favorably after showing the same infographic. Only three people chose Option B again, but the other 20 assistants raised their hands supporting Option D. None went for Option A and C this time. Assistants showed surprised faces when they realized that around 80% of the NARWs are entangled by fishing gears at least once during their lifetime.

Q2 - Who eats whom? The second question could be more complicated than the first one because it tests a deeper knowledge of biology. First, the question was asked, and none of the assistants went for Option A (Phytoplankton eats Zooplankton), 7 people selected Option B (Zooplankton eats whale feces), 14 people went for the correct option, the Option C (Phytoplankton eats whale feces), and eight chose Option D (Whale eats phytoplankton). The good results in this first part are due to most assistants being marine biologists or related. After showing the infographic and asking the question again, Option A counted zero voters. Six voted for Option B, 15 for Option C, and 9 for Option D. As it is possible to notice, we counted more than 23 voters. The conclusion is that some assistants were hesitating. However, the audience was correct in both moments, so we considered keeping the idea of showing this whale's contribution to the environment as a cycle in the infographics, changing only the drawing style (Figure 22c).

Q3 - How many scuba divers would fit inside a NARW? For the first time asking this question, the correct option, Option A (About 20), obtained only three votes. Option B (About 10) had four votes. Eleven people went for Option C (About 50), and 7 for Option D (More than 50). The second time, after revealing the correct answer through the infographic, seven went for Option A, zero for Option B, and Option C and D had one voter each. After the infographic showed a reduced number of assistants voting (only 9 out of 23), the conclusion was that either the question or the picture was not clear enough for the audience. It led to changes in the design and the question (Figures 21b and 39c).

6.3 Study C - Public Square

Results presented in Table 7 show that the users, in general, actually learned something new with the infographics, considering the good results at the post-quiz. However, we noticed some aleatory errors in sending answers at the pre-quiz. The pattern with Android phones is not sending the answer to the last question. On the other hand, iOS devices, when having errors, do not send all the responses for the first quiz. In terms of frequency, the iOS version seems not to have this type of error so often [39]. In the case of Table 8, it is perceptible that some users were curious about the app but didn't want to spend time on it. The evidence mentioned is most of the users answered by pressing the first option three times (Q1: A, Q2: A, Q3: A), or did a sequence (Q1: A, Q2: B, Q3: C), excepting user number 18, that due to unknown errors the database didn't receive the answers, and user number 19, that answered the quiz correctly. Naturally, this is a supposition. Users in this table may believe that the options they selected were correct, but they didn't continue with the experience for some reason.

Considering the 13 users who completed the experience, we can conclude that we reached the project's objective. However, we should have more participants to verify if the application's effects

[39] We used the UUID to identify if a device is an Android or an iOS in our database. In the case of Android, UUIDs are in lowercase letters and numbers (e.g., f5471ac055bc7e0eabc6774316555660), and in the case of iOS, UUIDs are in uppercase letters, numbers, and dashes (e.g., 36BF8ACE-5D34-4CB5-A9FC-EF1EB76EA867).

are maintained and obtain significant results. One factor of not getting more participants was the short time allowed for us to be in a public space. With more days in Praça do Povo, more users would have time to approach. Another possible reason for not having more participants is the absence of free WiFi spots in the zone. Internet is necessary to download the app, receive the questions, and send the answers. Regarding the results for each question, we noticed an increasing knowledge effect in all learning subjects.

In Q1, we recorded the significant impact using the infographic in Figure 20 due to the growing percentage from 15.38% to the maximum value of 100% of participants sending the correct answer. In Q2, the results revealed an increasing knowledge but not so significant as the other questions. It can be explained by the complex composition of the picture (Fig. 22c). The picture shows the cycle, but understanding each element requires much attention. Furthermore, the concepts of *zooplankton* [40] and *phytoplankton* [41] may confuse participants who do not have profound knowledge about marine creatures and differentiating them in a picture is challenging. In Q3, we confirmed positive results in the transition from pre-test to post-test. In this case, the possibility of not reaching 100% or close as in the case of Q1 is hard to believe that a fully grown NARW can be as small as seven scuba divers swimming one in front of the other. Naturally, we did not approach the participants to know what they answered at that moment to ask them why they still believed that it should be more than seven scuba divers. However, part of the public is not informed about the health problems that NARWs face nowadays (Section 3), which may be the reason for going for options where the size is bigger than the picture demonstrates.

Another point to approach is participants' ages. As mentioned in the Introduction (Section 1), one of the problems is that educating the public, in general, was challenging because most of the time, adults and the elderly are not included in activities to raise awareness about marine issues. Naturally, the objective was to create an interaction many users could use. Because we needed to test the impact of the structure itself, we did not approach the people but observed the flow of possible users during the day from a distance. From observations, we conclude that users from preadolescence to young and middle-aged adults (Fig. 31).

[40] **Zooplankton:** A heterotrophic plankton range from microscopic organisms to large species, such as jellyfish. (`https://biologydictionary.net/zooplankton/`).

[41] **Phytoplankton:** A microscopic plankton capable of photosynthesis found in oceans, seas, and freshwater and an essential component of aquatic ecosystems (`https://biologydictionary.net/phytoplankton/`).

7 Related Work and Comparisons

This section contains some similar projects and studies, comparing them with the NARW project presented in this dissertation regarding technologies, methodologies, and results.

Integrating augmented reality technology to enhance children's learning in marine education. This study [13] is about adapting concepts such as digital game-based learning into an ingenious way to introduce a marine learning program, including AR technology. The main users are children coursing lower grade primary school. In both studies, AR technology is used. The authors of the project employed AR markers (Fig. 33a) to present different 3D elements, similar to the NARW interaction's pictograms (Fig. 33b). The instructors needed at least 13 different AR markers, as the interaction included 13 different Taiwanese species of fish represented with 3D AR objects. In our case, we only need three pictograms for the activity.

(a) Example of one of the markers used in the study [13].

(b) Example of one of the pictograms used for the NARW interaction.

Fig. 33: Comparing the markers for AR recognition in both studies.

The significant differences start from the hardware and activity itself. In the case of this study, each marker is printed on a vest worn by a teaching assistant, while in the MAR Gate project, the pictograms were printed on different triangle-shaped woods. The idea in Lu et al.'s [13]study is that, as they had at least three teaching assistants and 13 markers while the experience occurred, these three assistants changed the markers progressively. In our case, the pictograms don't change with the interaction, and we have enough space in the structure to include them all. Furthermore, the 3D objects appear in both projects, but it is still possible to see the surroundings. 3D objects are interactable in Lu et al.'s project, while NARW is not. Regarding the hardware, there are some differences, such as the technology used and the installation time. In this study, researchers used a webcam to read the markers, while in our activity, users employed their smartphones to do the same. Software installation and hardware adjustment can be completed in 10-15 minutes. On the other hand, installing ARDome only takes less than 5 minutes if the provided Internet is favorable. It doesn't require significant hardware adjustments due to the possibility of the users using their smartphones. While Lu et al.'s project presents a storytelling mode to teach the content, we used infographics as augmented images. Another difference is using two games to reinforce knowledge in children in this study before passing a final test. In the NARW project, we didn't approach that modality because we left the gamification to the Caretta-Caretta interaction.

Comparing methodologies. Lu et al.'s [13] study obtained 51 participants from 7-8 years old, while we only got 20 participants, and 13 of them completed the interaction. The explanation can

be that the study with children was in a controlled setup, i.e., going to a specific classroom and doing the activities with the students. In our case, we assembled the dome structure in a public space and let the people approach the dome voluntarily. However, as mentioned in the Discussion section (Section 6), the ages of our participants could be between preadolescence and middle-aged adults. In both studies, four stages are distinguishable. Lu et al.'s study's stages are similar to our stages:

- **Stage 1:** Learning content pre-test. The difference is the way of presenting these tests. Lu et al.'s forms are submitted with paper and pencil to children, while in our case, it is presented digitally using the same application.
- **Stage 2:** AR interactive instructions, in the case of Lu et al.'s study, and scanning pictograms in the case of our research.
- **Stage 3:** In the case of this study, they used games to reinforce knowledge, while at this stage, we are presenting our post-test section.
- **Stage 4:** Lu et al. presented at this stage the post-test. We give a gift to the user for participating with a NARW in the form of a 3D model.

Pre and post-tests in both studies have the same questions. However, Lu et al. presented a different sequence for the questions in the post-test. We did the same order for the questions in both tests. We created these tests with the same purpose: Determine if the learners had acquired the target knowledge after the learning activity. Lu et al.'s test includes 11 questions, while ours include only three. Additionally, Lu et al. measured learning motivation with a questionnaire at the end.

Comparing results. In both studies, we confirmed an increasing performance regarding knowledge (Table 9). In the case of Lu et al.'s [13] results (Table 9a), most questions in the post-test obtained almost the complete quantity of students answering correctly. Only two questions (Q6 and Q10) had a lower performance. MAR Gate's results (Table 9b) confirmed a high performance in two of three questions (Q1 and Q3). Q2 is the one in which the performance was less significant.

Gaming vs. Storytelling: Understanding Children's Interactive Experiences in a Museum Setting. This study [8] aims to compare the effect of gaming and storytelling in museum settings. Researchers developed two app modalities used in the local natural history museum to achieve the objective.

Comparing technologies and process. As mentioned, this project included two modalities with a common subject and similar setups but different types of interaction. The main topic is the ocean and the creatures present in it. Therefore, the authors created the modalities Ocean Game (OG) and Ocean Story (OS). On the other hand, ARDome also included two different modalities. However, both treated various topics around specific species. Caretta-Caretta modality was about the trash present in the ocean and how this affects marine environments through a game. NARW's modality aims to inform users about this species through pictures without the text in the form of infographics. The study was focused on an audience of 10 to 12-year-old children who visited the *Natural History Museum* in Funchal, Madeira. As mentioned in our project, we did not impose an age limit on the population because our goal was to let the participants approach by themselves. The observed participants were from preadolescence to middle-aged adults. Radeta et al. [8] mentioned that they chose, with the help of the museum, 13 relevant species to the local marine fauna. For

	Pre-test answered correctly	Post-test answered correctly
Q1	21 (41.2%)	46 (90.2%)
Q2	6 (11.8%)	51 (100%)
Q3	24 (47.1%)	46 (90.2%)
Q4	18 (35.3%)	46 (90.2%)
Q5	48 (94.1%)	49 (96.1%)
Q6	42 (82.4%)	46 (90.2%)
Q7	31 (60.8%)	51 (100%)
Q8	13 (25.5%)	46 (90.2%)
Q9	12 (23.5%)	50 (98.0%)
Q10	37 (72.5%)	34 (66.7%)
Q11	16 (31.4%)	35 (68.6%)

(a) Analysis of pre-test and post-test from Lu et al. study (adapted) [13].

	Pre-test answered correctly	Post-test answered correctly
Q1	2 (15.4%)	13 (100%)
Q2	3 (23.1%)	6 (46.2%)
Q3	3 (23.1%)	10 (76.9%)

(b) Analysis of pre-test and post-test from Study C (Section 5.3).

Table 9: Comparison of results from both studies.

these 13 taxidermied exemplars, they paired them with 13 RFID proximity sensors to transmit the media content in real-time. OG consisted of a game with a treasure-hunt style where the children have the mission of searching the 13 marine species, including a beacon with an icon placed on it (Fig. 34). The icons appear on the mobile phone screen when the user is close to the respective beacon. When the beacon is activated, the children have the opportunity to read three curious scientific facts about the species they are observing.

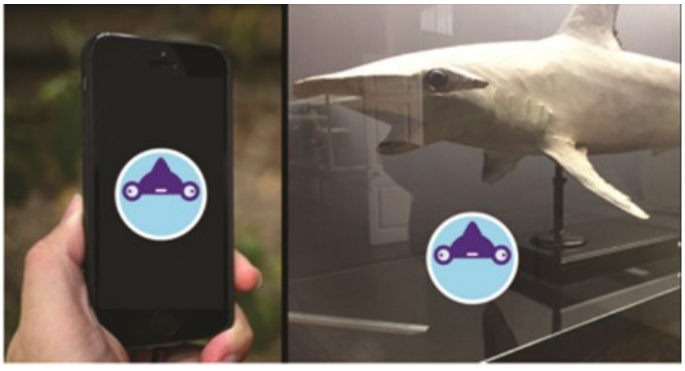


Fig. 34: Proximity beacons with an image attached to it. The phone detects the icon when the user is close enough to it (image retrieved from [8])

The OS interaction consisted of information triggered by the same beacons but, in this case, without the icons. The content is presented with a narration of a story while showing on their screens short and hand-drawn animations. The voice-over narration informs children with descriptions of the animal's physical characteristics. Overall, the narrative presented was about Madalena,

a child who missed pages about these animals (the same 13 species), and the children helped her to recover the lost notes each time they found one of the beacons. The group who participated in this interaction used a headset to get a more immersive experience.

MAR Gate's Study C experience was performed in an open space and using a dome structure with pictograms that were scanned to get the augmented images. The similar part between these studies is that both require smartphones to perform the activity. The difference is the way of approaching the activity. Participants in Radeta et al.'s study had to interact with proximity sensors, and in MAR Gate's Study C, the participants needed to scan pictograms on the wood with their cameras.

Comparing methodologies. Radeta et al. [8] obtained the participation of 28 children aged around 9-10 years old. The children were divided into two groups, 16 used the OG modality, and the remaining 12 used OS. Researchers did three different measurements:

- **M1:** Measurements in children's physiological arousal through skin conductance. They collected these measurements while they were using the application.
- **M2:** Pre and post-tests to measure the knowledge gained after the experience with 13 questions each, corresponding to the 13 marine species. OG participants answered on their smartphones, similar to what with did with the NARW experience. On the other hand, participants in OS used pencil and paper to follow the metaphor of Madalena's notebook.
- **M3:** After the experience, researchers measured the enjoyment and engagement with *Smileyometer* [42] and *Again-Again tables* [43], respectively. These surveys are retired from the User Evaluation Toolkit. Additionally, researchers used surveys on intrinsic motivation to obtain information about the children's enjoyment, engagement, and intrinsic motivation.

Comparing results. The only comparable measure collected is the **M2** with the pre and post-tests to analyze the children's knowledge after the experience. According to Radeta et al., OS group learning was insignificant, while OG had a larger effect size. Furthermore, the OS group forgot the knowledge, while the OG group gained more understanding of ocean literacy (Fig. 35).

Radeta et al. [8] recorded double learning outcomes in the OG group compared to the OS group. Children learned more with a gamified version when compared to the story-driven one. Although the NARW interaction does not enter the game or story-driven categories, it is demonstrated that using mobile devices in learning impacts children's performance significantly.

The Ocean Game: Assessing Children's Engagement and Learning in a Museum Setting Using a Treasure-Hunt Game. The study [9] was conducted using the OG modality, explained in the last section. In this opportunity, researchers compared the enjoyment and information learned by the children who participated in the study conducted in the *Natural History Museum of Funchal*, the same place as the last study.

[42] The smileyometer is a 5-point Likert Scale represented visually with smileys. The scale goes from 1 (Awful) to 5 (Brilliant). The first smiley shows a sad face, and the following are gradually changing their expression. The last one has an expressive smile, demonstrating satisfaction or enjoyment. This scale is usually used before and after the children interact with technology and measures satisfaction and fun [43].

[43] The Again-Again table is a way to collect children's opinions to measure the engagement by asking if they would the activity again or not [44].

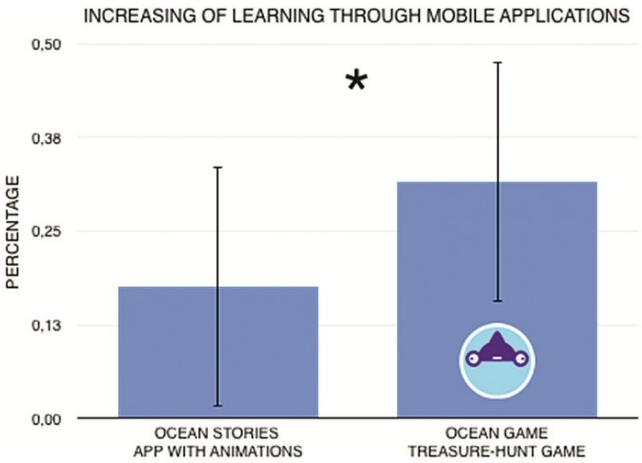
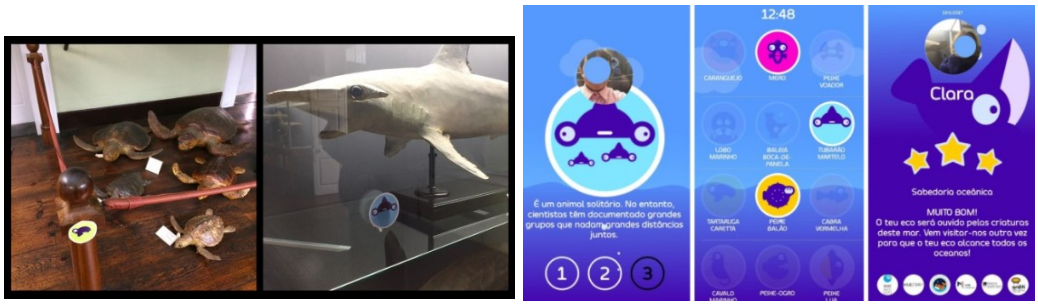


Fig. 35: Comparison of increasing of learning (retrieved from [8]).

Comparing technologies and process. The OG was described in the last section. To summarize, it is an application that works with proximity sensors using beacons with icons. These beacons are placed near selected species. Then, the user walks near the beacon, collects virtual coins and points, and learns facts about the species.



(a) Beacons placed near the species.

(b) Screenshots of the Ocean Game application.

Fig. 36: Pictures are from [9].

As mentioned before, in the ARDome application with the NARW interaction, we located the setup in an open space. Instead of proximity sensors, pictograms scanned with smartphones are placed in a geodesic dome structure.

Comparing methodologies. The study had 36 children as participants from a local school near the museum. These 36 children were divided into two groups. Group A had 16 children, and they used the OG mobile game. The other 20 children conformed the Group B. This group visited the museum with a guided tour done by a museum staff member without using smartphones. All participants answered pre and post-tests to assess the children's knowledge about local natural history and sea life before and after the experience. These tests were present in the mobile phones in the case of Group A and paper format in the case of Group B. The children were interviewed using surveys to assess their enjoyment, engagement, and intrinsic motivation when visiting the museum.

Comparing results. Cesário et al. [9] findings reveal that Group B obtained more excellent knowledge than Group A. However, in terms of motivation and enjoyment, Group A presented higher values than Group B (Table 10). As observations, researchers noticed that children in Group B were focused on what museum member staff was explaining during the 30 minutes of the tour. Just a few children diverged for a short time but always returned to the group. Group A participated in taking a self-portrait in which the children focused more on looking good. However, some participants kept their interest in observing the taxidermied species, and most were focused on completing the challenge of searching for the icons. In the self-portrait task, some children take photos focusing on the taxidermied animals and others on the icons.

	Group A Game	**Group B Traditional**	**Measure**	**Sig. (2-tailed)**
Again-Again Table				
Yes	100%	90%	Chi-Square	p = 0.193
Maybe	0%	10%		
No	0%	0%		
Smileyometer	Constant	MD = 5 IQR = 1	Mann-Whitney	p = 0.009
Intrinsic Motivation	MD = 5 IQR = 0.14	MD = 4.71 IQR = 0.29	Mann-Whitney	p = 0.001
Learning	M = 23.56 SD = 13.31	M = 35 SD = 16.46	Unrelated t-test	p = 0.031

Table 10: Summary of statistical tests applied in the Ocean Game study (retired from [9]).

Researchers discussed these results. The next list summarizes the relevant points of the discussion:

- The most immersed, engaged, and the motivated group was Group A. So it is possible to conclude that the OG application was more engaging and enjoyable. Still, the tour guide also supported a rich social interaction between children of Group B to keep the excitement while the tour continued.
- Despite enjoyment's high levels in Group A, a tension between the gaming and the learning aspects of the experience. Researchers observed that the children focused on the game and completed the missions as fast as possible. The authors recognize that the game could be improved to enhance learning, and one of the solutions offered is to change the text elements with a video.
- The game stimulated some behaviors in the children, such as competition and interest in collecting items. According to researchers, these behaviors can be advantageous for designers of mobile learning applications.
- Another noticeable fact is that adults have an important role to play in the general children's learning experience. The authors observed this situation with Group B and the museum staff member.

The conclusion obtained from analyzing this study, it would be interesting to conduct a similar study with the NARW interaction by comparing a group using the app and another with a traditional way of informing the general public, such as using a short presentation, flyers, or books. Furthermore, comparing classic museum tours with those enhanced with technologies helps to understand at what point mobile learning has effects on the users. However, in this example, engagement and enjoyment are confirmed, and these characteristics help children keep motivated.

8 Conclusion

This dissertation aims to answer each research question and summarize and reflect on the project and studies performed during the thesis period. Additionally, this final chapter recommends future work and contributions considering the methodology and achieved results.

Responding to **RQ1** about how are AR interactions influence users while using them in public spaces, considering the results of Study A, we found that using AR has effects on users' emotions. Participants in both groups expressed in the survey an emotional improvement after collecting the virtual trash to help the Caretta-Caretta turtle. Considering the immersion's results, it was noticeable that the external environment was irrelevant to the emotional effects. A good ambiance impacts the users due to the satisfactory results obtained evaluating this factor (Sections 5.1 and 6.1).

Study B's objective was to understand how the public interprets figures without texts to respond to the **RQ2**. After finalizing this study, we noticed if a picture is well-represented, the public will interpret it according to the original intentions, just like the case of the infographic related to NARW's threads (Fig. 20). This fact was witnessed while analyzing Study C's results when all participants selected the correct option after seeing this figure too. However, the other pictures did not obtain the same effect in Study B. Representing a 2D image with the idea that requires three dimensions, like the figure of the NARW filled with scuba divers (Fig. 21a), is challenging. Therefore, a recommendation is to consider how and with which tool the information will be presented without texts and test it with a group of potential users before the deployment. In Study C, the same idea but designed in another way (Fig. 21b) and a slightly different question focusing on the length of the NARW worked better (Section 5.3). Finally, the picture of the whale pump (Fig. 22b) wasn't challenging to represent, but the information presented required particular marine biology knowledge to be interpreted correctly. We obtained a reasonable interpretation of marine biologists in Study B (Section 5.2) but not so good in Study C (Section 5.3). The second version could be a more complex figure (Fig. 22c), but we didn't change the basic idea of the cycle. A suggestion when delivering a picture without texts to be interpreted is knowing first the mindset of the target public and attempting to at least be clear with the possibly unknown information.

The final research question (**RQ3**) refers to how effective AR is as a learning method in public spaces. To answer that question, we conducted Study C. Public spaces are an excellent location to educate a wider audience. Study C revealed positive results during the two days of being conducted (Section 5.3). However, the experience should be tested for a more extended period, at least two weeks, to have meaningful results.

Nevertheless, thirteen people voluntarily participated when they felt attracted by the structure, installed the app, and finished the two tests. These participants revealed improved knowledge of some aspects of the NARW, especially its current threats and size. Therefore, we can conclude that AR is a learning tool for educating people in public spaces, and it can be effective if it is joined to showy elements such as the geodesic dome.

A deep analysis of the adopted methodologies reveals that they favor answering the research questions. To summarize, the project started with conducting Study A using a pre-existent app version with a related topic to analyze the impact of AR on the public to respond to the initial research question (**RQ1**). Then, we brainstormed to generate ideas for the next modality of the NARW and decided to create virtual infographics without texts as Augmented Images. This idea

led to the second research question (**RQ2**), and Study B was conducted. Finally, we implemented a new modality in the ARDome app with the conclusions obtained from the previous two studies. The development led to the last research question (**RQ3**), the most important due to the initial goal of raising awareness in the general public about marine concerns. Study C demonstrated that it is possible to use elements such as public spaces and technologies to educate citizens about contemporary problems.

Relatively to the findings, it is recommended for future studies to use more appropriate scales, especially on questionnaires for study users' insights when performing experiences such as Study A (Section 4.3).

Last but not least, this dissertation contributes more ideas to approaching environmental concerns, revealing the results of using AR technologies and suggesting creative ways to raise awareness in public. To conclude, this dissertation includes these suggestions for future projects: the practice of similar projects regarding other topics of interest and implementing them in popular locations to focus them in different places instead of only in schools. In terms of studies, a comparison between traditional education and learning assisted with technologies in public settings should be conducted to test the effectiveness of both solutions and make the respective improvements. These studies are recommended due to the findings done by Cesário et al. [9] in a museum setting, where the traditional museum proved to be more effective in enhancing learning than using a mobile application with the same purpose. Another suggestion is to repeat the Study C methodology by adding a long-term survey to test whether the participant remembers the learned topic. Naturally, this possibly requires modifications in the application protocol by being necessary as a way to contact the participant via e-mail or phone call.

9 Attachment A

This appendix contains the installation process and code for ARDome's development.

9.1 Unity and ARCore cookbook

This section explains all the necessary steps to set up Unity and ARCore.

Installation process. The following list shows step-by-step how to install Unity and download the ARCore package:

1. Download and install Unity 2020.1.2 [44].
2. Download ARCore package [45].
3. Download Android Studio [46].
   (a) Open Android Studio.
   (b) Go to System Settings, then to Android SDK and finally SDK Platforms + SDK Tools.
   (c) Download Android SDK 10 (29), as the target version and Android SDK 7 (24) as the minimum version.
   (d) Download Android SDK Build-Tools 29.
4. Open Unity Hub and create a new project.
   (a) Select a 3D type project and give it a name. Select the file path to save this project.

Package	Version to have installed
Alembic	1.0.7
Android Logcat	1.1.1
JetBrains Rider Editor	1.2.1
Post Processing	2.3.0
Test Framework	1.1.16
TextMeshPro	3.0.1
Timeline	1.3.4
Unity Collaborate	1.3.8
Unity UI	1.0.0
Visual Studio Code Editor	1.2.1
Visual Studio Editor	2.0.2
XR Plugin Management	3.2.15

Table 11: Versions for the package to have installed.

Importing a package. The following list is to import the ARCore package:

[44] Link to the Unity versions: `https://unity3d.com/get-unity/download/archive`. It is necessary to install *Unity Hub* first. Furthermore, the *Android Build Support* and *Windows Build IL2CPPL* are required too. These appear in the installation options.

[45] `https://github.com/google-ar/arcore-unity-sdk/releases/download/v1.25.0/arcore-unity-sdk-1.25.0.unitypackage`

[46] `https://developer.android.com/studio`

1. Import the ARCore package. There is two ways of doing that:

   (a) Go to Assets, then to Import Package, and finally to Custom Package. Select the ARCore package in its file path.

   (b) Search the package in the file explorer and drag it to the Project tab [47].

2. Go to the Package Manager.

   (a) Install/Upgrade/Downgrade the packages in Table 11 [48].

Section	**Setting**	**What to do...**
Other Settings	Rendering	Uncheck Auto Graphics API. If Vulkan is listed under Graphics APIs, remove it (click on Vulkan and click on minus).
	Multithreaded rendering	Select this option to use multithreaded rendering.
	Package name	Create a unique app ID using Java package name format. For example, use com.example.helloAR.
	Scripting backend	When building for 64-bit devices, set the Scripting Backend set to IL2CPP. See ARCore 64-bit requirement for more information.
	Target Architectures	When building for 64-bit devices, select ARM64 (requires Scripting Backend set to IL2CPP). See ARCore 64-bit requirement for more information.
	Minimum API Level	Select Android 7.0 'Nougat' (API Level 24) or higher. For AR Optional apps, the Minimum API is 14. TARGET API: Android 10.0 (API Level 29).
	XR Settings (Deprecated) - ARCore Supported	Enable this option.

Table 12: Configurations to set up the project.

Project Settings Configuration. The next steps are necessary to configure the project:

1. Go to File and then to Build Settings.

2. Under Platform, select Android and then click on Switch Platform.

3. Click on Player Settings.

4. In the Android settings tab, configure the following settings (Table 12).

Custom Gradle Configuration. A Gradle plugin packages up reusable build logic, which can be used across many projects and builds. Gradle allows you to implement your own plugins, so you can reuse your build logic and share it with others [49].

[47] The Project Tab works as a file explorer. The assets, scenes, and scripts are inside the files. In this step, it is common to have many errors that will be gradually corrected with the following steps.

[48] To know if a package is installed or not, check if there is a checkmark or a pointing-up arrow after the version number. If not installed, the word "Install" is there instead of the checkmark or the arrow. To change a package version, click on the arrow next to the package's name and click on "See other versions." Then, search for the version, click on it, and install.

[49] `https://docs.gradle.org/current/userguide/custom_plugins.html`

1. Go to Preferences, then to External Tools, after that to Android, and finally to Gradle. Next, set custom Gradle to Gradle 5.6.4 [50].
2. Go to Edit, then to Project Settings, Android tab, Publishing Settings, and finally Build. Next, select both:
   (a) Custom Main Gradle Template.
   (b) Custom Launcher Gradle Template.
3. Apply the following changes to both generated files: mainTemplate.gradle, and launcherTemplate.gradle [51]
4. Remove the following comment if the file has it:

```
        // GENERATED BY UNITY. REMOVE THIS COMMENT TO PREVENT OVERWRITING WHEN EXPORTING
    AGAIN

```

5. Insert the following lines at the top of the code:

```
        buildscript {
            repositories {
                google()
                jcenter()
            }
            dependencies {
                //Must be Android Gradle Plugin 3.6.0 or later. For a list of
                //compatible Gradle versions refer to:
                //https://developer.android.com/studio/releases/gradle-plugin
                classpath 'com.android.tools.build:gradle:3.6.0'

            }
        }

        allprojects {
            repositories {
                google()
                jcenter()
                flatDir{
                    dirs 'libs'
                }
            }
        }

```

[50] To see the list of available versions: `https://gradle.org/releases/`. Save the download of the Gradle in a known path. Copy the path and paste it in the field (or click on Browse and find the file).

[51] Use the search bar in the Project tab to search these two files.

9.2 Scripts

Quiz scripts.

GetManager.cs

```
using System.Collections;
using System.Collections.Generic;
using System.Linq;
using UnityEngine;
using UnityEngine.Networking;
using UnityEngine.SceneManagement;
using UnityEngine.UI;

public class GetManager : MonoBehaviour
{
    private InputField outputArea; // Area where the question text is shown

    private string json; // String from json file (json needs to be converted)

    public Button[] answersButtons = new Button[4]; // Four buttons for the four options of each question

    public Text[] buttonsText = new Text[4]; // Text placed on the buttons

    private int questionID; // ID of the question

    private PostResponses postResponses; // Reference to the Post Responses script

    public List<int> questionsList = new List<int>(); // List of questions received from the database

    [System.Serializable]
    public class Data
    {
        public int id; // ID of the question
        public string question; // Text of the question
        public int scale; // Number of possible answers/options
    }

    [System.Serializable]
    public class DataList
    {
        public Data[] data; // Array of data (id, question and scale)
    }

    public DataList myDataList = new DataList(); // Instantiate the data list

    // Start is called before the first frame update
    void Start()
    {
        outputArea = GameObject.Find("OutputArea").GetComponent<InputField>(); // Finds the output area in the hierarchy
        postResponses = GetComponent<PostResponses>(); // Gets the script to post the answers to the database
        StartCoroutine(GetData_Coroutine()); // Starts the coroutine to get the questions from the data base
    }

    private IEnumerator GetData_Coroutine()
    {
        outputArea.text = "Loading..."; // While the app is getting the questions shows this text to demonstrate it is waiting

        var url = "http://wave.arditi.pt/api/form/ARDOME"; // URL address to get the questions
        using (UnityWebRequest request = UnityWebRequest.Get(url))
        {
            yield return request.SendWebRequest();
```

```
            if (request.isNetworkError || request.isHttpError)
            {
                Debug.Log("Error: " + request.error);
                outputArea.text = "Error: " + request.error;
            }
            else
            {
                json = request.downloadHandler.text;
                myDataList = JsonUtility.FromJson<DataList>(json);
                QuestionPrinter(0);
            }
        }
    }

    private void QuestionPrinter(int currentIndex) // "Prints" the question on the screen
    {
        // This index is from the data list
        if (currentIndex < myDataList.data.Length) // If the current index is lower than the current index
        {
            outputArea.text = myDataList.data[currentIndex].question; // Shows the question of the current index
            ButtonsPrinter(currentIndex); // Shows the buttons corresponding to the question of the current index
            questionID = myDataList.data[currentIndex].id; // Gets the question's id of the current index
            CreateArrayOfQuestions(questionID); // Creates an array with the ids of the questions

            // This for cycle gives the instruction to call a function from all of the four buttons to pass to the next question
            for (int i = 0; i < answersButtons.Length; i++)
            {
                int closureIndex = i;
                answersButtons[closureIndex].onClick.AddListener(() => PassToNextQuestion(currentIndex));
            }
        }
    }

    // This function "prints" the text for each button depending on the current question on the screen
    private void ButtonsPrinter(int currentIndex)
    {
        questionID = myDataList.data[currentIndex].id; // Gets the id of the question, not the index, to restrict them (this is, in case of change or add more questions in the database, we avoid the confusion of giving wrong options to an specific question)
        switch (questionID)
        {
            case 132: // Question: How many North Atlantic Right Whales are caught by fish net at least once in their lifetime?
                buttonsText[0].text = "1 out of 10";
                buttonsText[1].text = "3 out of 10";
                buttonsText[2].text = "5 out of 10";
                buttonsText[3].text = "More than 5 out of 10";
                break;
            case 133: // Question: Who eats whom?
                buttonsText[0].text = "Phytoplankton eats Zooplankton";
                buttonsText[1].text = "Zooplankton eats whale feces";
                buttonsText[2].text = "Phytoplankton eats whale feces";
                buttonsText[3].text = "Whale eats phytoplankton";
                break;
            case 134: // Question: How many scuba divers are equivalent to the length of a North Atlantic Right Whale?
                buttonsText[0].text = "About 7";
                buttonsText[1].text = "About 12";
                buttonsText[2].text = "About 20";
                buttonsText[3].text = "More than 20";
```

```
                break;
            }
        }

        // ReSharper disable Unity.PerformanceAnalysis
        // Function to pass to the next question
        private void PassToNextQuestion(int i)
        {
            i++; //Increment the index
            if (i < myDataList.data.Length) //In case that the index still less than the length of the data array...
            {
                QuestionPrinter(i);//... prints another question on the screen
            }
            else // Otherwise, sends the answers to post to the database and changes the scene
            {
                StartCoroutine(postResponses.PostData_Coroutine());
                ChangeScene();
            }
        }

        // Depending on the current scene, this function changes it to the next one
        private void ChangeScene()
        {
            var sceneName = SceneManager.GetActiveScene().name; // Gets the name of the current scene

            switch (sceneName)
            {
                case "Pre": // In case we are on the pre-questions (or pre-quiz), the next scene is the Message scene (scene with instructions about the scanning part)
                    SceneManager.LoadScene("Message");
                    break;
                case "Post": //In case we are on the post-questions (or post-quiz), the next scene is the Celebration scene (3D model of the whale).
                    SceneManager.LoadScene("Celebration");
                    break;
            }
        }
        // Forms an array with the id of the questions
        private void CreateArrayOfQuestions(int questionID)
        {
            questionsList.Add(questionID);
        }

}
```

PostResponses.cs

```
using System;
using System.Collections;
using System.Collections.Generic;
using System.Linq;
using UnityEngine;
using UnityEngine.Networking;
using UnityEngine.UI;

public class PostResponses : MonoBehaviour
{
    public Button[] buttons = new Button[4];

    private List<int> answersList = new List<int>();

    private GetManager getManager;

    private void Start()
    {
        getManager = GetComponent<GetManager>();
```

```
    }

    public void AddAnswerToArray(int index)
    {
        answersList.Add(index);
    }

    public IEnumerator PostData_Coroutine()
    {
        var arrayOfAnswers = answersList.ToArray();
        foreach (var answer in arrayOfAnswers)
        {
            print("QUESTIONS POST DEBUG: Answer: " + answer);
        }
        var jsonAnswers = JsonUtility.ToJson(arrayOfAnswers);

        var listOfQuestions = getManager.questionsList;
        var arrayOfQuestions = listOfQuestions.ToArray();
        foreach (var question in arrayOfQuestions.Distinct())
        {
            print("QUESTIONS POST DEBUG: Question: " + question);
        }
        var jsonQuestions = JsonUtility.ToJson(arrayOfQuestions.Distinct());

        //var url = "http://wave.arditi.pt/api/result";
        WWWForm form = new WWWForm();
        var uuid = SystemInfo.deviceUniqueIdentifier;
        form.AddField("uniqid", uuid);
        form.AddField("form_id", 6);
        form.AddField("source_id", 5);
        form.AddField("ratings[0]", arrayOfAnswers[0]);
        form.AddField("ratings[1]", arrayOfAnswers[1]);
        form.AddField("ratings[2]", arrayOfAnswers[2]);
        print("QUESTIONS POST DEBUG: ratings added");
        form.AddField("questions[0]", arrayOfQuestions[0]);
        form.AddField("questions[1]", arrayOfQuestions[1]);
        form.AddField("questions[2]", arrayOfQuestions[2]);
        print("QUESTIONS POST DEBUG: questions added");

        using (UnityWebRequest request = UnityWebRequest.Post("http://89.109.64.184:80/api/
    result", form))
        {
            print("QUESTIONS POST DEBUG: Entered using UnityWebRequest");
            yield return request.SendWebRequest();
            print("QUESTIONS POST DEBUG: SendWebRequest");
            if (request.isNetworkError || request.isHttpError)
            {
                print("IMAGES POST DEBUG: Error in post image: " + request.error);
            }
            else
            {
                print("IMAGES POST DEBUG: Image data sent successfully!");
            }
        }
    }
}
```

Scan scripts

AugmentedImageVisualizer.cs

```
using System.Collections;
using System.ComponentModel;
using System.Runtime.CompilerServices;
using JetBrains.Annotations;
using UnityEditor;

namespace GoogleARCore.Examples.AugmentedImage
```

```
{
    using System;
    using System.Collections.Generic;
    using System.Runtime.InteropServices;
    using GoogleARCore;
    using GoogleARCoreInternal;
    using UnityEngine;



    /// <summary>
    /// Shows 3 different infographics for 3 different pictograms
    /// </summary>
    public class AugmentedImageVisualizer : MonoBehaviour
    {
        public GameObject Info, Contributions, Threat; //The 3 Infographics

        public AugmentedImage Image;//The image which we are reading/scanning

        private Dictionary<int, GameObject> imagePrefabPairs; //A dictionary to establish a relation between one pictogram and its infographic

        void Start()
        {
            instantiateDictionary();
        }

        void Update()
        {
            TrackingDetector();
        }



        //Creates a dictionary to make a infographic - pictogram relation
        private void instantiateDictionary()
        {
            imagePrefabPairs = new Dictionary<int, GameObject>
            {
                { 0, Info}, //The first image of the Database corresponds to the Info infographic
                { 1, Contributions},//The second image of the Database corresponds to the Contributions infographic
                { 2, Threat},//The third image of the Database corresponds to the Threads infographic
            };
        }

        private void TrackingDetector()
        {
            var imageIndex = Image.DatabaseIndex;
            //Verifies if we are tracking
            if (Image.TrackingState != TrackingState.Tracking) //If we are not tracking yet...
            {
                imagePrefabPairs[imageIndex].SetActive(false); //... the infographic does not appear
            }

            float halfWidth = Image.ExtentX / 2; //Measures the width of the pictogram and finds the middle point
            float halfHeight = Image.ExtentZ / 2; //Measures the height of the pictogram and finds the middle point
            imagePrefabPairs[imageIndex].transform.localPosition = (halfWidth * Vector3.zero) + (halfHeight * Vector3.zero); //Joins the halfWidth and halfHeight results to find the center of the image
            imagePrefabPairs[imageIndex].SetActive(true);
            print("Tracking state: " + Image.TrackingState.ToString());
        }
```

```
    }
}
```

InfoPost.cs, ContributionPost.cs and ThreatPost.cs

```
using System;
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class InfoPost : MonoBehaviour
{
    // When the infographic poster is enable on the scene, start a coroutine to post its id to the database and start a countdown timer to appear a message...
    public void OnEnable()
    {
        print("Active info");
        StartCoroutine(PostImages.PostData_Coroutine(0));
        print("POST DATABASE");
        StartCoroutine(MessageBox.ShowMessage(25f));
    }
}
```

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class ContributionPost : MonoBehaviour
{
    // When the infographic poster is enable on the scene, start a coroutine to post its id to the database and start a countdown timer to appear a message...
    public void OnEnable()
    {
        print("Active contribution");
        StartCoroutine(PostImages.PostData_Coroutine(1));
        print("POST DATABASE");
        StartCoroutine(MessageBox.ShowMessage(25f));
    }
}
```

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class ThreatPost : MonoBehaviour
{
    // When the infographic poster is enable on the scene, start a coroutine to post its id to the database and start a countdown timer to appear a message...
    public void OnEnable()
    {
        print("Active threat");
        StartCoroutine(PostImages.PostData_Coroutine(2));
        print("POST DATABASE");
        StartCoroutine(MessageBox.ShowMessage(25f));
    }
}
```

PostImages.cs

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.Networking;

public class PostImages : MonoBehaviour
{
    // Coroutine to send the id of the infographic opened by the user to the database
```

```
    public static IEnumerator PostData_Coroutine(int index)
    {
        var url = "http://wave.arditi.pt/api/record/ardome/image"; // URL address to send the id
        WWWForm form = new WWWForm();
        var uuid = SystemInfo.deviceUniqueIdentifier; // Identifies each device with a unique combination of numbers and letters
        var dateTime = System.DateTime.Now.ToString("yyyy-M-d hh:mm:ss"); // Sends the date and time of the moment of the lecture

        form.AddField("uniqid", uuid);
        form.AddField("datetime", dateTime);
        form.AddField("image_id", index);
        using (UnityWebRequest request = UnityWebRequest.Post(url, form))
        {
            yield return request.SendWebRequest();
            if (request.isNetworkError || request.isHttpError)
            {
                print(" POST DEBUG: Error in post image: " + request.error);
            }
            else
            {
                print("IMAGES POST DEBUG: Image data sent successfully!");
            }
        }
    }
}
```

PageSwiper.cs

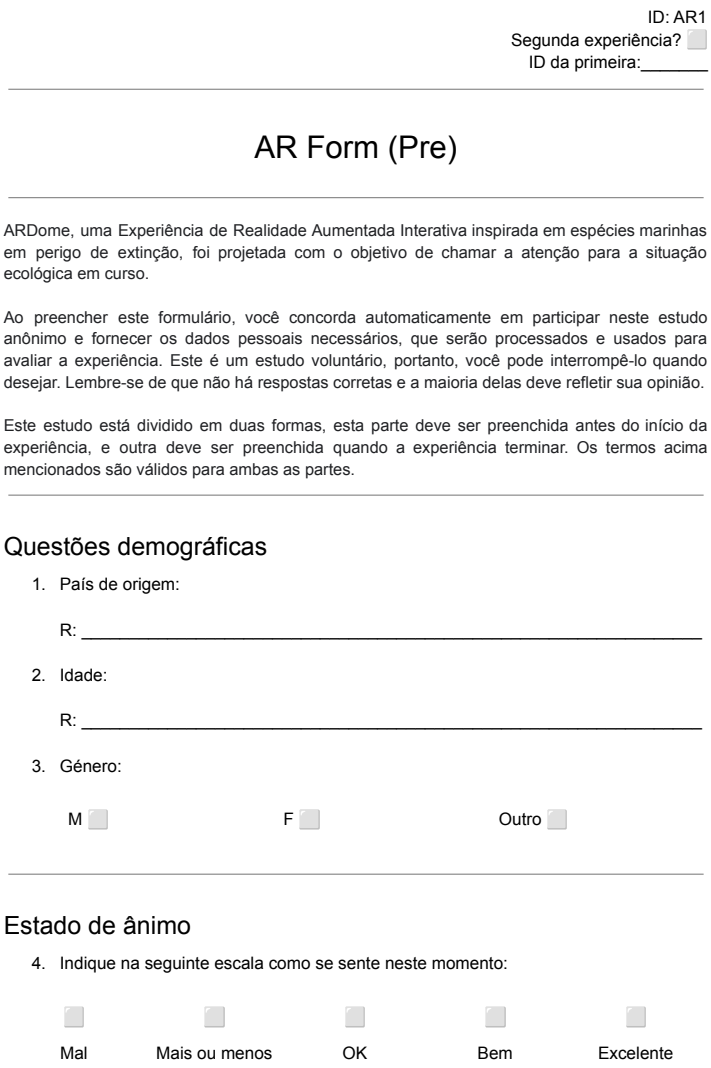
```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.EventSystems;

public class PageSwiper : MonoBehaviour, IDragHandler, IEndDragHandler
{
    private Vector3 panelLocation; // Variable for the current panel location

    public float percentThreshold = 0.2f; // Limit of percentage

    public float easing = 0.5f; // Number of seconds that allow a smoother movement

    public int currentChild; // Current child panel (Whale and Turtle)
    // Start is called before the first frame update
    void Start()
    {
        panelLocation = transform.position; // Gets current position
    }

    public void OnDrag(PointerEventData data) // Calculate drag movement
    {
        Debug.Log(data.pressPosition - data.position); // Debug the position values (see console)
        float difference = data.pressPosition.x - data.position.x; // Variable of the difference between the current press position and the position on x of the pointer
        transform.position = panelLocation - new Vector3(difference, 0, 0);// Movement on x of the panel (current panel location minus vector3 with the difference variable on x; y and z are 0 because we don't want any variations on those axes)
    }

    public void OnEndDrag(PointerEventData data) //When the drag movement ends...
    {
        float percentage = (data.pressPosition.x - data.position.x) / Screen.width; // Calculation of the percentage of the dragging movement in relation to the screen width

        if (Mathf.Abs(percentage) >= percentThreshold)
        {
```

```
            Vector3 newLocation = panelLocation; // Variable of the new location

            // These conditionals anchors first and last screens (the first panel won't move to the left and the last won't pass to the right)
            if (percentage > 0 && currentChild < transform.childCount - 1)
            {
                newLocation += new Vector3(-Screen.width, 0, 0);
                currentChild++;
            }
            else if(percentage <0 && currentChild > 0)
            {
                newLocation += new Vector3(Screen.width, 0, 0);
                currentChild--;
            }

            // If the percentage is greater than the percent threshold, a smooth movement will happen and the panel will have a new location
            StartCoroutine(SmoothMove(transform.position, newLocation, easing));
            panelLocation = newLocation;
        }
        else
        {
            StartCoroutine(SmoothMove(transform.position, panelLocation, easing));
        }
    }

    // Coroutine to give an smooth movement while dragging
    IEnumerator SmoothMove(Vector3 startpos, Vector3 endpos, float seconds)
    {
        float t = 0f;
        while (t <= 1.0)
        {
            t += Time.deltaTime / seconds;
            transform.position = Vector3.Lerp(startpos, endpos, Mathf.SmoothStep(0f, 1f, t));
            yield return null;
        }
    }
}
```

SceneController.cs

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;

public class SceneController : MonoBehaviour
{
    //Load a scene by its name
    public void LoadScene(string sceneName)
    {
        SceneManager.LoadScene(sceneName);
    }
}
```

10 Attachment B



ID: AR1
Segunda experiência? ⬜
ID da primeira:_____

AR Form (Pre)

ARDome, uma Experiência de Realidade Aumentada Interativa inspirada em espécies marinhas em perigo de extinção, foi projetada com o objetivo de chamar a atenção para a situação ecológica em curso.

Ao preencher este formulário, você concorda automaticamente em participar neste estudo anônimo e fornecer os dados pessoais necessários, que serão processados e usados para avaliar a experiência. Este é um estudo voluntário, portanto, você pode interrompê-lo quando desejar. Lembre-se de que não há respostas corretas e a maioria delas deve refletir sua opinião.

Este estudo está dividido em duas formas, esta parte deve ser preenchida antes do início da experiência, e outra deve ser preenchida quando a experiência terminar. Os termos acima mencionados são válidos para ambas as partes.

Questões demográficas

1. País de origem:

   R: _____

2. Idade:

   R: _____

3. Género:

   M ⬜ F ⬜ Outro ⬜

Estado de ânimo

4. Indique na seguinte escala como se sente neste momento:

   ⬜ Mal ⬜ Mais ou menos ⬜ OK ⬜ Bem ⬜ Excelente

Fig. 37: Pre-form for the Study A.

52

[52] These questionnaires are short to allow the possibility of answering briefly. The team behind the design and development created the questions and the answers. These questions are not retired from other official questionnaires. They were written accordingly to the needs of the study. A better practice is to research the most used questions with verified scales.

ID: AR1
Segunda experiência? ⬜
ID da primeira:_____

AR Form (Post)

Estado de ânimo

1. Indique na seguinte escala como se sente após de realizar a experiência:

⬜	⬜	⬜	⬜	⬜
Mal	Mais ou menos	OK	Bem	Excelente

Questões sobre a experiência:

2. Indique na seguinte escala que tão imersiva foi a experiência para você:

⬜	⬜	⬜	⬜	⬜
1 Pouco imersiva	2	3	4	5 Muito imersiva

3. Indique quanto tempo você acha que passou interagindo com a aplicação:

⬜	⬜	⬜	⬜	⬜	⬜
< 5 minutos	5 minutos	10 minutos	15 minutos	20 minutos	> 20 minutos

4. Indique na seguinte escala o que tão absorvido pelo ambiente se sentiu:

⬜	⬜	⬜	⬜	⬜
1 Pouco absorvido	2	3	4	5 Muito absorvido

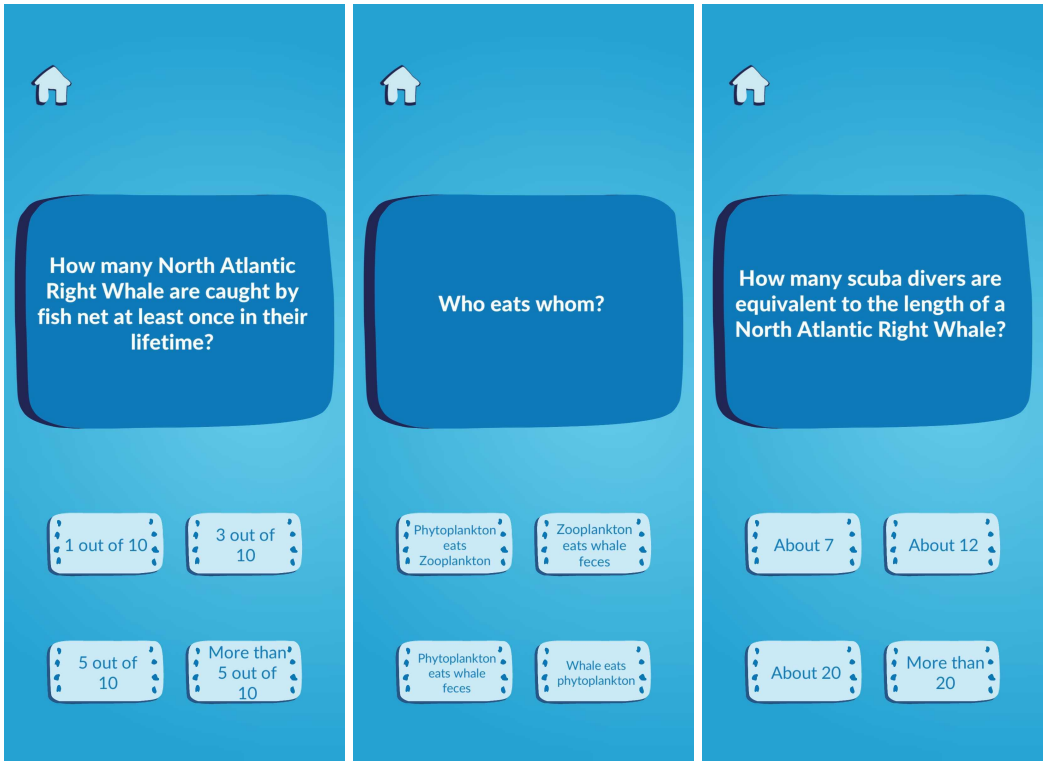
Fig. 38: Post-form for the Study A.

11 Attachment C

Nationalities	AR group participants	ARS group participants
Portuguese	15	19
Venezuelan	1	1
South African	1	-
Spanish	1	-
Mexican	1	-
German	1	-

Table 13: The number of participants by nationality.

12 Attachment D



(a) Question 1. (b) Question 2. (c) Question 3.

Fig. 39: Quiz questions. The quiz is the same before and after scanning the pictograms to test the user's knowledge.

References

[1] D. A. Plecher, M. Wandinger, and G. Klinker, "Mixed reality for cultural heritage," in *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 2019, pp. 1618–1622.

[2] P. Milgram and F. Kishino, "A taxonomy of mixed reality visual displays," *IEICE TRANSACTIONS on Information and Systems*, vol. 77, no. 12, pp. 1321–1329, 1994.

[3] P. Milgram, H. Takemura, A. Utsumi, and F. Kishino, "Augmented reality: A class of displays on the reality-virtuality continuum," in *Telemanipulator and telepresence technologies*, vol. 2351. International Society for Optics and Photonics, 1995, pp. 282–292.

[4] N. Winters, "What is mobile learning," *Big issues in mobile learning*, vol. 7, no. 11, 2007.

[5] J. Cooke, "The iucn red list of threatened species," Jan 2020. [Online]. Available: https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T41712A178589687.en

[6] F. Christiansen, S. M. Dawson, J. W. Durban, H. Fearnbach, C. A. Miller, L. Bejder, M. Uhart, M. Sironi, P. Corkeron, W. Rayment *et al.*, "Population comparison of right whale body condition reveals poor state of the north atlantic right whale," *Marine Ecology Progress Series*, vol. 640, pp. 1–16, 2020.

[7] J. Roman and J. J. McCarthy, "The whale pump: marine mammals enhance primary productivity in a coastal basin," *PloS one*, vol. 5, no. 10, p. e13255, 2010.

[8] M. Radeta, V. Cesario, S. Matos, and V. Nisi, "Gaming versus storytelling: understanding children's interactive experiences in a museum setting," in *International conference on interactive digital storytelling*. Springer, 2017, pp. 163–178.

[9] V. Cesário, M. Radeta, S. Matos, and V. Nisi, "The ocean game: Assessing children's engagement and learning in a museum setting using a treasure-hunt game," in *Extended Abstracts Publication of the Annual Symposium on Computer-Human Interaction in Play*, 2017, pp. 99–109.

[10] R. Danovaro, "Pollution threats in the mediterranean sea: an overview," *Chemistry and Ecology*, vol. 19, no. 1, pp. 15–32, 2003.

[11] L. S. Weilgart, "The impacts of anthropogenic ocean noise on cetaceans and implications for management," *Canadian journal of zoology*, vol. 85, no. 11, pp. 1091–1116, 2007.

[12] D. W. Laist, A. R. Knowlton, J. G. Mead, A. S. Collet, and M. Podesta, "Collisions between ships and whales," *Marine Mammal Science*, vol. 17, no. 1, pp. 35–75, 2001.

[13] S.-J. Lu and Y.-C. Liu, "Integrating augmented reality technology to enhance children's learning in marine education," *Environmental Education Research*, vol. 21, no. 4, pp. 525–541, 2015.

[14] O. Mironenko and E. Mironenko, "Education against plastic pollution: current approaches and best practices," in *Plastics in the Aquatic Environment-Part II*. Springer, 2020, pp. 67–93.

[15] V. J. Shute, "Tensions, trends, tools, and technologies: Time for an educational sea change," *ETS Research Report Series*, vol. 2006, no. 1, pp. i–49, 2006.

[16] M. Radeta, M. Andrade, R. Freitas, M. Sousa, A. Ramos, V. Azevedo, J. Lopes, R. Jardim, J. Gouveia, M. J. Gouveia *et al.*, "Interaquatica-designing interactive aquatic experiences with geodesic domes in-the-wild," in *ACM International Conference on Interactive Media Experiences*, 2020, pp. 170–173.

[17] R. Skarbez, M. Smith, and M. C. Whitton, "Revisiting milgram and kishino's reality-virtuality continuum," *Frontiers in Virtual Reality*, vol. 2, p. 27, 2021.

[18] V. de Carvalho Silva, "Realidade virtual, do sensorama a carverna digital créditos."

[19] J. Carmigniani, B. Furht, M. Anisetti, P. Ceravolo, E. Damiani, and M. Ivkovic, "Augmented reality technologies, systems and applications," *Multimedia tools and applications*, vol. 51, no. 1, pp. 341–377, 2011.

[20] J. Herron, "Augmented reality in medical education and training," *Journal of Electronic Resources in Medical Libraries*, vol. 13, no. 2, pp. 51–55, 2016.

[21] S. J. Henderson and S. K. Feiner, "Augmented reality for maintenance and repair (armar)," Columbia Univ New York Dept of Computer Science, Tech. Rep., 2007.

[22] M. Bulearca and D. Tamarjan, "Augmented reality: A sustainable marketing tool," *Global business and management research: An international journal*, vol. 2, no. 2, pp. 237–252, 2010.

[23] K. Lee, "Augmented reality in education and training," *TechTrends*, vol. 56, no. 2, pp. 13–21, 2012.

[24] M. Speicher, B. D. Hall, and M. Nebeling, "What is mixed reality?" in *Proceedings of the 2019 CHI conference on human factors in computing systems*, 2019, pp. 1–15.

[25] W. Liu, A. D. Cheok, C. L. Mei-Ling, and Y.-L. Theng, "Mixed reality classroom: learning from entertainment," in *Proceedings of the 2nd international conference on Digital interactive media in entertainment and arts*, 2007, pp. 65–72.

[26] T. Stretton, T. Cochrane, and V. Narayan, "Exploring mobile mixed reality in healthcare higher education: a systematic review," *Research in Learning Technology*, vol. 26, pp. 2131–2131, 2018.

[27] M. D. O. Carrasco and P.-H. Chen, "Application of mixed reality for improving architectural design comprehension effectiveness," *Automation in Construction*, vol. 126, p. 103677, 2021.

[28] W. Hoenig, C. Milanes, L. Scaria, T. Phan, M. Bolas, and N. Ayanian, "Mixed reality for robotics," in *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2015, pp. 5382–5387.

[29] V. Cherniavskyi, H. Popova, M. Sherman, S. Voloshynov, and A. Yurzhenko, "Mixed reality technologies as a tool to form professional competency of sea transport professionals." in *ICTERI*, 2020, pp. 217–231.

[30] L. J. Brown, "Professional reflection–mixed reality to augment the next generation of aviation professionals," in *Engaging the Next Generation of Aviation Professionals*. Routledge, 2019, pp. 163–180.

[31] I. Wohlgenannt, A. Simons, and S. Stieglitz, "Virtual reality," *Business & Information Systems Engineering*, vol. 62, no. 5, pp. 455–461, 2020.

[32] M. Sharples, I. Arnedillo-Sánchez, M. Milrad, and G. Vavoula, "Mobile learning," in *Technology-enhanced learning*. Springer, 2009, pp. 233–249.

[33] A. Kukulska-Hulme and J. Traxler, "Mobile learning," *A handbook for educators and trainers*, 2005.

[34] M. Sharples, J. Taylor, and G. Vavoula, "Towards a theory of mobile learning," in *Proceedings of mLearn*, vol. 1, no. 1, 2005, pp. 1–9.

[35] A. Rashid, M. A. Zeb, A. Rashid, S. Anwar, F. Joaquim, and Z. Halim, "Conceptualization of smartphone usage and feature preferences among various demographics," *Cluster Computing*, vol. 23, no. 3, pp. 1855–1873, 2020.

[36] L. Naismith and D. Corlett, "Reflections on success: A retrospective of the mlearn conference series 2002-2005," 2007.

[37] J. D. Stewart, J. W. Durban, A. R. Knowlton, M. S. Lynn, H. Fearnbach, J. Barbaro, W. L. Perryman, C. A. Miller, and M. J. Moore, "Decreasing body lengths in north atlantic right whales," *Current Biology*, vol. 31, no. 14, pp. 3174–3179, 2021.

[38] W. R. K. S. D. K. A. R. Pace III, Richard M. and H. Pettis, "Cryptic mortality of north atlantic right whales," *Conservation Science and Practice*, vol. 3, no. 2, 2021.

[39] E. L. Meyer-Gutbrod, C. H. Greene, K. T. Davies, and D. G. Johns, "Ocean regime shift is driving collapse of the north atlantic right whale population," *Oceanography*, vol. 34, no. 3, pp. 22–31, 2021.

[40] J. Roman, J. A. Estes, L. Morissette, C. Smith, D. Costa, J. McCarthy, J. Nation, S. Nicol, A. Pershing, and V. Smetacek, "Whales as marine ecosystem engineers," *Frontiers in Ecology and the Environment*, vol. 12, no. 7, pp. 377–385, 2014.

[41] G. E. Maul and D. E. Sergeant, "New cetacean records from madeira," *Bocagiana-Funchal*, 1977.

[42] A. I. Nordin, J. Ali, A. Animashaun, J. Asch, J. Adams, and P. Cairns, "Attention, time perception and immersion in games," in *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, 2013, pp. 1089–1094.

[43] B. Zaman, V. V. Abeele, and D. De Grooff, "Measuring product liking in preschool children: An evaluation of the smileyometer and this or that methods," *International Journal of Child-Computer Interaction*, vol. 1, no. 2, pp. 61–70, 2013.

[44] J. C. Read and S. MacFarlane, "Using the fun toolkit and other survey methods to gather opinions in child computer interaction," in *Proceedings of the 2006 conference on Interaction design and children*, 2006, pp. 81–88.