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Eco Detectives
Fostering Environmental Awareness in Youth Through Augmented Reality and Non-linear Narratives

MASTER DISSERTATION

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MASTER OF INTERACTIVE MEDIA DESIGN

UNIVERSIDADE da MADEIRA
A Nossa Universidade
www.uma.pt

September | 2025

UNIVERSIDADE da MADEIRA
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Faculty of Exact Sciences and Engineering

Master of Interactive Media Design

Eco Detectives: Fostering Environmental Awareness in Youth Through Augmented Reality and Non-linear Narratives

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Friday 16th January, 2026

Sumário

Com o passar do tempo, cada vez mais fauna e flora têm atingido o estado de espécies ameaçadas, em parte devido à ação humana direta e indireta. Esta ameaça é algo que grandes grupos como a UNESCO têm procurado combater através da integração da educação ambiental em todos os países. É importante salientar que a transmissão de conhecimento sobre este tema às crianças é uma forma de estabelecer comportamentos que podem amadurecer e persistir mais tarde nas suas vidas. A maior parte da informação partilhada sobre este assunto é demasiado científica e técnica para as crianças compreenderem o que pode levar ao tédio e à falta de interesse, mas é aqui que as experiências interativas e educativas baseadas na natureza podem oferecer uma potencial solução. Com o uso de Narrativas Interativas, podemos entreter os utilizadores enquanto estes se imergem num mundo ficcional, ao mesmo tempo que recebem lições de vida que os beneficiarão, a eles e ao ambiente que os rodeia. Para reforçar ainda mais as suas qualidades imersivas, combinámos Narrativas Interativas com Realidade Aumentada (RA), devido à forma como esta pode simular e sobrepor realidades imersivas no nosso próprio mundo.

Em colaboração com o Parque Ecológico do Funchal, criámos "Eco Detectives", uma aplicação para smartphone, para explorar o potencial da combinação de RA, Narrativas Interativas não lineares e tecnologias baseadas em localização. Esta experiência imersiva baseada na natureza leva crianças (dos 9 aos 13 anos) numa aventura para resolver um mistério de assassinato e roubo enquanto interagem com espécies de um ecossistema biodiverso, ensinando-as sobre as ameaças à flora e fauna locais.

Os testes com utilizadores revelaram que os minijogos em RA e a narrativa não linear foram altamente envolventes para os participantes. No entanto, as funcionalidades de RA mantêm um equilíbrio delicado com o conteúdo educativo e narrativo, com risco de os participantes se focarem excessivamente na exploração e em tarefas interativas quando não estão devidamente equilibradas. Surgiram desafios, particularmente para os utilizadores mais jovens, destacando considerações importantes para projetos futuros semelhantes.

Keywords: Biodiversidade · Realidade Aumentada · Experiência baseada em localização · Narrativa Interativa · Aprendizagem

Abstract

As time passes, more and more fauna and flora have reached endangered status, in some part due to direct and indirect human action. This threat is something that major groups such as UNESCO have been trying to tackle through the integration of environmental education in all countries.

It is important to emphasize that providing knowledge on this topic to children is a way to lay down behaviors that may mature and persist later in their lives. Most information that is shared about this subject is too scientific and technical for children to understand and might lead to boredom and disinterest, but this is where nature-based educational interactive experiences may offer a potential solution. With the use of Interactive Narratives, we can entertain users as they immerse themselves in a fictional world while also receiving life lessons that will benefit them and the surrounding environment. To further enhance its immersive strengths, we combined Interactive Narratives with Augmented Reality (AR) due to the way the latter can simulate and superimpose immersive realities into our own world.

Working together with Parque Ecológico do Funchal, we created "Eco Detectives", a smartphone application, with the aim to explore the potential of the combination of AR, Interactive Narratives, and Location-Based technologies. This nature-based immersive experience takes children (ages 9-13) on an adventure to solve a murder and thief mystery while interacting with species from a biodiverse ecosystem, teaching them about threats to local flora and fauna.

User testing revealed that AR mini-games and the non-linear narrative were highly engaging for participants. However, AR features maintain a delicate balance with educational and narrative content, with risk of participants focusing excessively on exploration and interactive tasks when not properly balanced. Challenges emerged, particularly for younger users, highlighting important considerations for similar future projects.

Keywords: Biodiversity · Augmented Reality, · Location-based experience · Interactive Storytelling · Learning

Acknowledgments

First and foremost, I would like to express my sincere gratitude to my supervisor, Mara Dionisio. Her unwavering support, insightful guidance, and intellectual rigor were instrumental throughout this process. This thesis would not have been possible without her constant encouragement. I am also deeply thankful for her efforts in helping to secure a large part of the participant base and for her valuable assistance as an on-site researcher during the study, which greatly improved the management of the participants.

I also want to extend a special thanks to my co-supervisor, Paulo Alexandre Câmara Bala. His extensive technical knowledge and generous mentoring were crucial for the development of my game project, Eco Detectives. I am particularly grateful for his invaluable assistance with the implementation of Yarn Spinner and the AR mechanics, which were essential to the project's success. Furthermore, I would like to thank him for his patience and expertise in helping me resolve issues with my thesis LaTeX file.

I would like to thank Sandra Olim. Her help in organizing the necessary documentation for the study was invaluable. I am also grateful for her support as an on-site researcher, which was instrumental in helping me manage the participants effectively.

I would also like to thank Joana Gomes for her valuable assistance with the implementation of a specific feature in Eco Detectives.

My sincere thanks also go to E-games Lab for providing me with an investigation scholarship, which greatly helped with the project's costs. Their support extended far beyond financial aid; they allowed me to use their space and facilities during the development of my project and facilitated contact with many seasoned researchers whose ideas and comments were incredibly helpful.

I would also like to thank André Freitas, Diogo Santos, and Anna Jiskrova for their collaboration during the development of Mistério do Parque Ecológico, the original prototype version of Eco Detectives, during our Interactive Narratives I class. I am especially indebted to André Freitas; as the sole programmer, he was the biggest source of support for the project. His immense patience in implementing my ideas—which formed the core of the project's design—was essential, and without his expertise, the game simply would not have been made. I am also grateful to Diogo for his work

on the backgrounds and for helping with some of the sprites, and to Anna for her contributions to the UI icons and her support with the research and data collection that were essential for the project's development.

I would like to express my sincere thanks to Parque Ecológico do Funchal for their incredible cooperation and openness. They were instrumental in the success of my project, providing the space for the study and accommodating our participants. I am especially grateful to the park's chief, João Miguel Gouveia Nunes, for his belief in the project and his patience. My deepest thanks also go to Afra Carisia Faria Martins Rocha for serving as my main point of contact at the park and for being so pleasant and helpful with every request.

I would like to extend a special thank you to all the participants who took part in this study. Their time and honest feedback were invaluable and a vital component of this research.

On a personal note, I would like to thank my family for their unwavering support. To my father, thank you for your love and support. To my sister and her family, thank you for your encouragement. A special thank you to my mother, who has always been my biggest supporter and has been there for me through both the best and worst of times. Your endless love, patience, and readiness to help whenever I needed it made this journey possible.

Finally, this research was funded by the Portuguese Recovery and Resilience Program (PRR), IAPMEI/ANI/FCT under Agenda no.26, C645022399-00000057 (eGamesLab). I would also like to acknowledge the Portuguese Foundation for Science and Technology for projects 10.54499/LA/P/0083/2020; 10.54499/UIDP/50009/2020 & 10.54499/UIDB/50009/2020.

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List of Acronyms

AR Augmented Reality

IFCN Institute of Forest and Nature Conservation

IN Interactive Narratives

IUCN International Union for Conservation

LBE Location Based Entertainment

MDMI Master of Interactive Media Design

MX Mixed Reality

PEF Parque Ecológico do Funchal

QR Quick Response

RFID Radio Frequency Identification

UI User Interface

UNESCO United Nations Educational, Scientific and Cultural Organization

VR Virtual Reality

XR Extended Reality

1 Introduction

According to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species published in 2023 [51], over 44,000 species out of a total of 157,000 assessed species, encompassing both flora and fauna, are currently classified as endangered. This represents an increase of more than 2,000 species from the previous assessment [52], with anthropogenic activities serving as primary drivers of this alarming trend [7].

International organizations, including the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the IUCN, have implemented various conservation strategies to preserve global ecosystems. In Madeira, the Parque Ecológico do Funchal (PEF) has made significant efforts to protect local species within the Funchal Ecological Park from endangerment and extinction. However, these institutional efforts remain insufficient to address the magnitude of the biodiversity crisis [24]. The expanding human population continues to exert substantial pressure on natural environments through resource extraction, economic development, and various anthropogenic activities [18]. These impacts manifest through seemingly minor actions such as improper waste disposal, uncontrolled domestic animal populations, and failure to implement responsible pet ownership practices [25,43]. The persistence of these behaviors can be attributed to limited environmental awareness and insufficient public engagement with conservation issues [33]. It is essential to emphasize that addressing environmental degradation requires collective responsibility rather than individual culpability, as blame-focused approaches may inadvertently promote disengagement and inaction [12].The science community maintains that effective conservation interventions remain feasible [17], contingent upon widespread public education and behavioral change. Education serves as a fundamental mechanism for knowledge transfer, preparing individuals for societal participation while promoting culturally accepted moral and civic behaviors through both theoretical and practical components [41].

Educational experiences during childhood play a crucial role in shaping behavioral patterns, knowledge acquisition, and environmental attitudes that persist into adulthood. Children's environmental behaviors are significantly influenced by educational interventions at both local and global scales [13]. Research demonstrates that direct contact with natural environments facilitates the development of stronger emotional connections and empathetic responses toward the natural world [44], enabling the acquisition of appropriate environmental behaviors through guided learning

experiences. However, a significant challenge in traditional environmental education stems from the inherent complexity of ecological concepts, often presented with daunting scientific terminology. This can lead to a psychological barrier for young learners, as traditional approaches frequently fail to connect these abstract ideas to their everyday experiences, causing disengagement [72]. This means that new experiences should strive for more engaging structures, and the use of narratives can provide said needed structure [14]. With the use of narratives, previous studies have proposed that children are more likely to retain the facts and messages learned [54] and produce high level of engagement through immersion [45]. This also opens the opportunity for less typical ways to educate children to arise, such as through the use of Interactive Narratives (IN).

This thesis builds upon a prior project developed during the Interactive Narratives I course within the Master of Interactive Media Design (MDMI) program. The initial project involved the development of an interactive narrative designed for the Funchal's Ecological Park, with the objective of educating visitors about the area's biodiversity and wildfire conservation.

The resulting project was a mobile game application targeting a tween demographic (9-to-13 years old), in which participants were tasked with investigating the circumstances surrounding the death of Azul, an endangered Zino's Petrel [29]. Entitled "O Mistério do Parque Ecológico" (The Mystery in the Ecological Park), the game employed a treasure hunt-style mystery format, incorporating elements inspired by geocaching methodologies [68]. Participants were required to locate Quick Response (QR) codes distributed through the Ecological Park, which, when scanned, unlocked interactive scenes featuring various witnesses and potential suspects, utilizing visual novel-presentation formats. In this project I took the roles of game designer, main writer, UI designer, and character designer, with my colleagues filling in on other roles such as background artist, programmer, and others.

Following the development of the original prototype, institutional interest emerged regarding its continued development and enhancement, with particular emphasis on integrating eXtended Reality (XR) technologies to enrich user experience. This technological advancement aimed not only to increase awareness of the Ecological Park and its biodiversity but also to establish a dynamic educational platform that promotes immersive and meaningful engagement with the region's natural heritage.

eXtended Reality (XR), and Augmented Reality (AR) in particular, hold significant promise for enhancing engagement with natural heritage [14]. These technologies can be easily accessed by a broad audience, making them especially effective for educational and interpretive purposes in outdoor environments such as ecological parks. AR's capacity to overlay digital information onto real-world settings creates opportunities [80] for users to interact with natural surroundings. Furthermore, the widespread availability of AR-capable devices—most commonly smartphones and tablets—supports the scalability and accessibility of such experiences. A 2021 study reported that 95 percent of children over the age of 10 in Portugal owned a smartphone [73], reflecting the increasing integration of digital technologies into daily life and highlighting the potential of AR as a powerful educational tool for younger audiences.

This thesis examines the design process and evaluation of "Eco Detectives", incorporating Augmented Reality (AR), Interactive Narratives, and Location-Based technologies to engage children aged 9 to 13 with natural heritage. This demographic represents a critical developmental period for fostering emotional and cognitive connections with the natural world, consistent with the biophilia hypothesis [15], which states that humans have a deep genetic predisposition to understand and connect to nature and natural processes, which can blossom into deeper relations through direct and quality contact with the natural world.

This thesis is guided by the following research questions:

Research Question 1: How does the combination of AR, player motion, non-linear interactive narratives, and location-based experiences affect user experience and behavior, particularly the balance between engagement with interactive elements and absorption of narrative content?

Research Question 2: How does the combination of AR, non-linear interactive narratives, and location-based experiences affect children's comprehension and retention of scientific knowledge and moral lessons related to ecological issues?

Research Question 3: What are the pedagogical, technical, and design challenges and benefits of creating a location-based experience using AR and a non-linear interactive narrative for children aged 9-13?

The contribution of this work lies in providing empirical data and evidence about the effectiveness of AR-based location-based educational experiences for children, specifically identifying the challenge of balancing engaging interactive elements with educational content delivery.

This thesis represents the culmination of this research, building directly upon two preliminary publications [21, 22];

1) A. Freitas, F. Fernandes, M. Dionísio, and S. Olim, "Mystery in the ecological park: An interactive narrative to promote interaction with biodiversity," in Entertainment Computing – ICEC 2023: 22nd IFIP TC 14 International Conference, ICEC 2023, Bologna, Italy, November 15–17, 2023, Proceedings. Berlin, Heidelberg: Springer-Verlag, 2023, p. 360–364. [Online]. Available: https://doi.org/10.1007/978-981-99-8248-6_32

2) L. F. Fernandes, P. Bala, S. C. Olim, P. F. Campos, and M. Dionisio, Combining Interactive Narratives and Augmented Reality to Promote Engagement between Children and Nature. New York, NY, USA: Association for Computing Machinery, 2025, p. 858–862. [Online]. Available: https://doi.org/10.1145/3713043.3731496

By expanding the scope and further refining the systems used on a full user study, this work presents a complete, cohesive body of research.

1.1 Thesis Structure

Following the introduction, the Literature Review will provide a comprehensive and interconnected overview of existing research pertinent to our study. This section examines key areas such as the dynamics between nature and child interaction, the power of games in fostering nature engagement and motivation, the power of Interactive Narratives, and the educational potential of location-based media and eXtended Reality (XR), ending with highlighting the current research gaps that this thesis aims to bridge.

The core of our practical work is presented in the section "Eco Detecives: Design Process and Implementation". Here we begin with the research focus then narrow the scope to detail the specific methodology employed in this study. This section also provides a detailed account of the development of our interactive experience, "Eco Detectives." It traces the evolution of the prototype from its initial iterations to the current low-fidelity and high-fidelity versions. We describe the narrative, visual design, character development, User Interface (UI) design, and the

Augmented Reality (AR) design, including the specific AR interactions implemented. This section concludes by discussing the user experience considerations and the technical implementation that brought the project to life.

Following the development, the Study section outlines the experimental procedure used to evaluate the developed prototype. This part clearly details the study setup, the execution of the experiment, our data collection methods, and the post-game interview process designed to gather crucial participant feedback.

The findings from our study are then presented in the Results section. This part begins by describing the participants involved and then moves into a presentation of our overall observations from the experiment. It provides a thorough analysis of participant feedback across various critical aspects, including their general enjoyment, understanding and appreciation of the narrative, perceptions of the visuals and characters, and engagement with the AR and map mechanics. We also include participants' concluding thoughts, suggestions, and expressed interest.

The Discussion interprets these results, directly linking them back to our research questions. This section offers an in-depth analysis of how our findings address each of the three primary research questions. The findings offer valuable insights for future developers of location-based educational AR applications. Looking ahead, the Future Work section identifies potential avenues for further research and development that emerged from this thesis, suggesting directions for continued exploration. Finally, the Conclusion brings the thesis to a close by summarizing the key findings and contributions of our research, reaffirming the significance of this study and its broader implications.

2 Literature Review

In order to develop an effective educational tool for engaging children with ecological issues, it is essential to ground this research within existing literature that intersects environmental education, interactive media, and digital technologies. This chapter presents a review of relevant theoretical and practical works across five key domains: child-nature interaction, game-based learning for sustainability, Interactive Narratives, Location-Based Experiences, and eXtended Reality (XR). Each section explores how these components have been previously applied to learning environments, particularly for younger audiences, and highlights how their integration offers unique opportunities for immersive, place-based ecological education.

2.1 Nature and Child Interaction

As stated above, planting environmentalist mindsets in children is an important milestone for continuous good behaviors between them and the environment. The biophilia hypothesis [15] states that humans have a genetically rooted inclination to interact with, associate with, and connect to nature and natural processes. However, for this tendency to fully develop, it is imperative that individuals have direct and positive contact with nature. Without such experiences, negative attitudes and indifference towards nature may emerge.

Research has also suggested that biophilia has a critical relationship with specific periods in an individual's life, highlighting early childhood as a key window of opportunity to form bonds with nature. This underscores the importance of educating and engaging young children with the natural world [77].

2.1.1 Benefits and Barriers to Nature Connections for Children

Through direct outdoor interaction with nature, children are more likely to develop biophilic relationships with the nature around them through the means of contact, emotion, meaning, compassion, and beauty [44]. Nature is also important in the psychological growth of a child. Research found that nature is beneficial to mental health, calming the effects of depression and anxiety [9,27].

Despite the recognized benefits of nature engagement, children today face significant barriers to experiencing the natural world. A key obstacle lies in the educational complexity surrounding environmental and ecological concepts. These concepts are frequently presented using complex scientific

terminology and abstract concepts that can intimidate young learners [35]. This perception of difficulty creates a psychological barrier where children may feel that environmental science is beyond their comprehension level. Traditional educational approaches often fail to bridge the gap between complex scientific phenomena and children's everyday experiences, leading to disengagement before meaningful learning can occur [72]. The abstract nature of many environmental concepts, such as ecosystem interdependence, climate systems, or biodiversity loss, requires innovative pedagogical approaches that can make these ideas tangible and accessible to young minds [34].

This challenge is further compounded by the widespread impact of urbanization. Modern lifestyle changes, emerging in the late 20th century, have increasingly shifted children's time indoors and away from nature. This is directly linked to the fact that half of the world's population now resides in urban environments, further limiting access to natural spaces [16]. Within these urban settings, key obstacles include safety concerns, extended hours spent in formal education, a scarcity of suitable outdoor environments, and restricted access to green spaces.

It is precisely in overcoming these multifaceted barriers that locations with abundant natural resources , like Madeira, offer a significant advantage. With approximately 67 percent of its land dedicated to nature reserves and protected areas [75], Madeira presents an incredible opportunity to foster biophilic bonds between children and nature.

The Institute of Forests and Nature Conservation (IFCN) has created programs that try to promote interest in the topic of conservation by taking children of various ages on field trips to nature-filled areas and teaching them about the actions being taken to take care of said areas [53]. Unfortunately, with current lifestyles, constant interaction with nature isn't always possible, which is why smaller interventions are also important to create bonds between nature and children. In Funchal, the Nature Conservation and Climate Change Division and Environmental Awareness Unit have conducted 2 quiz tournaments directed to children with the objective to disseminate knowledge and stimulate the creation of nature-friendly behavior later [23].

2.1.2 Games in Natural Sustainability and Education

Games are naturally suited to support learning by making it more engaging and interactive. They can motivate players and help them understand complex ideas through active participation [49]. These games give instant feedback and help players visualize complicated systems, making it easier

to move from simply knowing about sustainability to actually practicing it. This can boost confidence and encourage meaningful changes in how people think and act. To promote this connection between nature and children, some have turned to the world of "gaming" as a solution, like the mobile game Nature Collections, where children were incentivized to take pictures to complete challenges and gain badges for their achievements. Using gamification, this experience was able to increase the amount of time children would spend outside in nature [32]. iNaturalist and Seek offer compelling models for gamified citizen science, demonstrating success in increasing student engagement with nature and improving species identification. Their use of image recognition and badge systems highlights the power of gamification in fostering motivation and learning [11, 66]. In a similar vein, EcoMOBILE provides a robust mobile learning environment for outdoor environmental education, leveraging Augmented Reality (AR) and Location-Based features to enhance environmental science understanding and positive attitudes toward outdoor learning [31]

From an academic angle, outdoor nature experiences have also been shown to improve children's understanding and willingness to learn scientific content and knowledge beyond the level of those who only have typical lectures [14], even in children that have a general lack of interest or difficulties grasping the subject [71].

In general, gamified approaches to environmental education offer both inspiration and a strong methodological foundation for creating more engaging experiences. However, this concept alone is not sufficient. It is important to emphasize real-world interaction as essential for fostering biophilic connections in children, along with a well-structured educational framework to support meaningful understanding. This is where the integration of additional concepts, such as interactive narratives, Location-Based Experiences, and eXtended Reality (XR) technologies, can serve as powerful, comprehensive educational tools.

2.2 Interactive Narratives

According to H. Porter Abbot, "Narrative is the representation of events, consisting of story and narrative discourse. Story is an event or sequence of events (the action), and narrative discourse is those events as represented." [1]. With a narrative, we create stories involving characters that inhabit a world going in some sort of journey that the user may experience in linear or nonlinear way. Using narratives, writers can give structure to any sort of message they wish to give to

their audience, including the distribution of any sort of educational knowledge. Not only that, but narratives can also foster perspective-taking and long-term retention when paired with emotional content [30].

Interactive Narratives consist of the telling of a story where users may interact with specific aspects of it while the story continues along; a good example of this is video games. These interactions may or may not impact the outcome of the narrative, but they should still have to provoke some reaction or cause some sort of effect on the overall experience. With it we design experiences focused on the player's needs, psyche, state of flow, and enjoyment, allowing them to directly interact with the events of a narrative discourse [6]. Said narratives can be used in a variety of mediums, such as movies, videos, comics, and games [3].

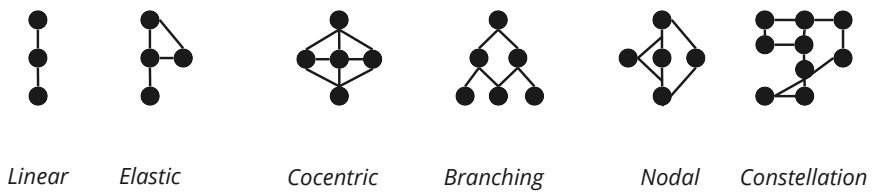

Figure. 1: Interactive Narrative Typologies

Interactive narratives can follow various typologies, as illustrated in the Figure (See Fig.1), which may or may not allow players to influence or branch the storyline. These typologies represent different levels of narrative control and player agency. Linear narratives follow a fixed path without branching. Elastic narratives allow temporary deviations but return to the main storyline. Concentric narratives share fixed beginnings and endings while varying the middle sections. Branching narratives split into distinct paths based on player choices, leading to different endings. Nodal structures consist of interconnected story nodes accessible in various orders. Constellation narratives offer maximum freedom, allowing narrative elements to be discovered in nearly any sequence, though this approach sacrifices narrative coherence for player autonomy. A notable example of this loss of narrative control can be seen in the critically acclaimed open-world commercial game The Legend of Zelda: Breath of the Wild [56]. In this game, players explore a fully open world that enables them to choose which challenges to tackle and how to approach them. Although this

level of freedom fosters individual playthrough experiences, it also allows players to encounter key narrative moments at vastly different times, or potentially not at all. As a result, the game's story progression can feel less cohesive, since players may reach later narrative events before experiencing earlier ones that provide essential context and setup. This approach also benefits from using less detailed or complex narratives, as it reduces the need for multiple characters to respond dynamically to unfolding events, thereby minimizing the narrative workload and development complexity.

2.2.1 Interactive Narratives and Environmental Education

Previous research has suggested the potential of Interactive Narratives as a ludic/pedagogic tool [63], allowing students to learn and be entertained at the same time, something that would be beneficial to a younger target audience. With a narrative, we can personalize a serious and complex issue into a more palatable and fun form to better catch and sustain a player's interest. Hootopia [78] is a project that uses a tangible interactive board game format to explore the effectiveness of interactive digital storytelling in fostering a deeper, experiential understanding of biodiversity and species protection in children. The game's objective is to cultivate a profound connection between players and the imperative of safeguarding animal habitats, rather than simply disseminating academic content. The game features a physical-digital hybrid system with a tangible map and physical modules, like animals and characters embedded with Radio Frequency Identification (RFID) antennas. The narrative casts players in the dual roles of "environment transformers" and "animal protectors" who compete and cooperate between themselves to protect animal habitats. The game's beginning phase features a poem that reinforces the central theme: regardless of who wins the game, animals may still be lost, underscoring the non-zero-sum nature of environmental issues. By framing biodiversity as a non-zero-sum variable, the game demonstrates that individual player success is hollow if it results in a collective ecological collapse, thereby shifting the focus from personal victory to shared survival between players. The project successfully demonstrates the feasibility of merging tangible gameplay with interactive storytelling to make the abstract concept of biodiversity more concrete, tangible, and engaging for children.

Another example is the commercial game Beyond Blue, which employs storytelling and gameplay to highlight the beauty of the ocean. In this experience, players dive into the depths of the sea to discover and observe a variety of marine creatures inhabiting the vast underwater ecosystem [46].

It is important to emphasize that deep and complex narratives are not always necessary to convey environmental themes. Visual storytelling can be equally, if not more, effective than verbal exposition in communicating such messages. The commercial game Sonic the Hedgehog (1991) [70] exemplifies this through its level design and difficulty progression, which subtly reinforce its underlying nature-versus-machine theme. The game begins with Green Hill Zone, a vibrant tropical landscape filled with rolling hills that promote fast-paced movement and feature minimal obstacles. As the game progresses, the environments gradually incorporate more mechanical elements and hazards, culminating in Scrap Brain Zone, a harsh, fully industrialized level that represents the dystopian future awaiting the world should Dr. Robotnik succeed. Through this visual and gameplay evolution, the game presents a compelling narrative about the encroachment of technology on nature.

Beyond narrative design, the complexity of gameplay mechanics also does not determine an experience's educational value. Previous studies have suggested that visual novels—which feature relatively simple interaction patterns—can serve as effective structures for educational games due to them increasing players' understanding, focus, and mindfulness [69].

Narratives can instill a sense of obligation in regard to nature in users, however, it is important to note there is a difference between culpability and responsibility [62]. A narrative trying to pass the responsibility of our world to the next generation should always be careful to not focus on "blaming" humanity in general for the current state of the world, or a specific group, but instead focus on giving youths a true sense of responsibility by telling them what they can do. In the commercial mobile game Planet Stories AR [39], users help take care of a turtle, and at no point does the game point fingers at who's at fault for the endangerment of turtles, but instead gives advice, such as using metal straws, to help these shelled species in seemingly indirect ways.

The foundation of Interactive Narratives provides a powerful framework for environmental education, which becomes even more compelling when combined with Location-Based technologies that allow these stories to unfold in real-world natural settings. The logical progression is to integrate the digital story with the physical world, making the reader's real-world movements and location part of the narrative. This is where Location-Based Experiences come in. In terms of narratives, Location-Based Experiences provide an incredible dimension to stories: space. By leveraging the physical environment, developers can further immerse users into the narrative. This approach, as

research outlines [58], treats space not merely as a setting, but as an integral design element, a concept that has since blossomed with modern GPS and Augmented Reality technologies.

2.3 Location-Based Experiences

Location-Based Entertainment (LBE) refers to experiences that rely on real-world coordinates that can be gained through GPS, Wi-Fi, or any other wireless infrastructure, mostly while using a mobile device, to process geo-coded content based on the user's current location and utilizes said data as part of the experience [60].

Location-Based games encourage users to explore and interact with their surrounding location because they can integrate real-world environments with game objectives, creating a sense of adventure and discovery. This interaction with the natural world can enhance engagement, foster curiosity, and, when combined with educational content, teach important messages and themes. Additionally, these experiences allow for more flexible learning, enabling users to engage with material at their own pace and according to their personal interests [4].

Location-Based Experiences have been developed for a range of devices, including computers, wearable technology such as the Super Mario bands from the Super Nintendo World theme park [65], and smartphones, which are particularly appealing due to their easy accessibility. This accessibility facilitates the widespread deployment and setup of Location-Based Experiences.

2.3.1 Implementation and Accessibility

As mentioned previously, Interactive Narratives can also provide opportunities with Location-Based Experiences. One academic project [42], proposed a novel structure where a branching narrative, described as a "story tree", was dispersed along a real-world location, which required users to walk towards specific zones to continue down a specific branch, swapping simple clicks with routing for choices, showcasing a potential avenue for how nonlinear interactive narratives can interact with the real world. This project also put great importance on the locations themselves, making sure that events occurred in areas that were thematically or directly sensible.

In terms of education, Location-Based Experiences have been recognized as beneficial tools, as they provide students with the opportunity to learn outside traditional school environments, offering field trip-like experiences [4].

There have been many academic projects that have leveraged Location-Based Experiences, such as the game ESS-Hunt [47]. Developed on the Google Maps platform, its core objective was to leverage real-world geographic data to enhance young citizens' awareness of urban tree ecosystem services. Through an interactive experience tied to physical locations, the game gave players riddles and tasks to go around the park to find specific locations, disseminating complex ecological concepts for participants aged 10-14. The study highlights the practical utility of municipal tree cadaster data for educational content, suggesting a scalable model for future Location-Based interventions. ES-Hunt serves as a compelling example of how digital solutions, rooted in mapping technologies like Google Maps, can effectively foster environmental literacy through direct engagement with physical surroundings.

The commercial game Pokémon GO [55] is probably the most popular example of a Location-Based Experience. In the original Pokémon games, players would explore different regions based on real-world locations to encounter regional-specific creatures known as Pokémon, with the intention to catch as many as they please. When this concept was taken to smartphones, not only did the game gain lots of revenue, but it also reached mainstream status, being played by people who wouldn't consider themselves "gamers" [61]. Pokémon GO takes the 1000-plus creatures created over the years and spreads them all around the world, meaning that there are some Pokémon that players will simply be unable to catch if they only stick to their hometown, encouraging players to step out of their comfort zone and into the wider world around them, whether it means that they need to travel between towns, cities, or even countries.

An issue with Pokémon GO and wide-reaching Location-Based Experiences that randomly generate object locations is that they might lead players to dangerous or prohibited areas, something that must be kept in mind when creating Location-Based Entertainment (LBE). Games like The Collect [59] take a safer and more limited approach. Instead of taking place all over the world, The Collect takes place in a zoo, where players must find barcodes to collect information on the real-life animals living in the zoo. Even though limited by today's standards, it still invoked the same "Gotta Catch'em All" feeling presented in Pokémon GO, and since the locations are far more handpicked instead of generally chosen, it allows for a safer experience.

Location-Based Experiences are also known to incentivize social interaction and connection with others [38]. This is something that is also seen with Pokémon GO, where players playing the game would often interact with each other, even if they are strangers.

The mobile social game, GreenCompass [76], offers a model that uses the social strength of Location-Based Experiences to encourage players to engage with nature during short, daily intervals. The game features personalized tasks that adapt to users' abilities and preferences, allowing them to seamlessly integrate nature-related activities into their routines. By combining social features with Location-Based Experiences, GreenCompass successfully boosted a sense of community among players, demonstrating the potential for these games to foster social connection and well-being.

2.4 eXtended Reality

eXtended Reality (XR) isn't a term that refers to one technology but instead a blanket term that refers to a group of computer-based technologies, which in some way simulate or interact with the real world. Using XR, educators can bridge the gap between theoretical and practical knowledge by allowing students to interact with the complex content they have learned in real time [28, 67]. The technologies under this term include Virtual Reality, Augmented Reality and Mixed Reality [41].

2.4.1 Virtual Reality

Virtual Reality (VR) is an immersive experience generated with computer technology to simulate real-world sensations to immerse users in a fictional world. The most popular way to enjoy VR nowadays is through the use of Head-Mounted Devices (HDM), such as the Sony VR and Quest series of models; however, other ways do exist, such as the use of the Cave Automatic Virtual Environment (CAVE), where users are put inside a room surrounded by projection walls to simulate a similar effect to that of the headsets [2]. One of the major barriers to entry of VR is the monetary cost of HDMs and the Cave. Fortunately, there are some cost-effective ways to enjoy VR, such as the use of smartphones with Google Cardboard [26], or with low-end consoles like the Nintendo Switch's Nintendo LABO [57], which both use cardboard to build a pseudo headset.

With VR we can potentially create worlds independent from reality to allow users to witness and interact with the beauty of nature and ecological threats, something done by the commercial

game Trash Rage VR [40] where players take a tour on a post-apocalyptic earth where the planet is nearly completely polluted. Research demonstrates that the use of 6-minute 360^{o} VR videos had similar beneficial calming mental effects to those who spent 6 minutes in actual nature [8]. The commercial game Nature Trek [10] takes advantage of these calming effects to immerse players on a trip to a beautiful nature-filled VR world.

2.4.2 Augmented Reality

Augmented Reality (AR) enhances the real world by superimposing digital visuals, sounds, and other sensory stimuli through a device, blending our reality with a virtual one and allowing creators to overlay virtual objects onto real environments [41]. AR experiences can be activated in various ways, depending on the technology used. There are three main types of AR experiences: Marker-based AR, which relies on scanning physical markers to superimpose multimedia elements directly onto them; Markless AR overlays AR objects onto a flat surface in the real world without needing a marker and can also be implemented in predefined real-world locations using a user's GPS coordinates.

2.4.3 Mixed Reality

Mixed Reality (MR), also known as Hybrid Reality [49]refers to the integration of both Virtual Reality (VR) and Augmented Reality (AR) technologies to display virtual objects within real-world environments. Head-mounted display devices like the Microsoft HoloLens [48] enable interaction with these virtual objects using hand and foot gestures.

Due to their low popularity and lack of widespread technology, there isn't a lot of research regarding MR.

2.4.4 Augmented Reality's potential

Augmented storying [37], which integrates AR applications with narrative, promotes children's interactions and connections with nature. It provides a unique avenue for children to express their voice in relation to nature and encourages them to explore natural environments. A study with Finnish children demonstrated how an AR character, nature, peers, and the children themselves interacted in playful, imaginative, and creative ways, fostering engagement with and for nature. This approach helps children develop personal and cultural literacies that become entangled with

broader social and ecological literacies, nurturing a deeper connection to nature [36]. Another, and probably one of the most well-known nature-based experiences that uses AR and storytelling, is Kiki's Adventure, an academic game that takes children on a trip to a specific location to learn about the importance of eucalyptus trees. Using the space around the users, the game allows players to use their phone's camera to interact with the eucalyptus trees, such as hanging Kiki the koala on them. The game had great success in teaching children all about the eucalyptus trees, their importance, and how they may be in danger [14].

Additionally, AR's physical interactivity encourages embodied learning, where children learn through their senses, movement, and actions. Some studies have suggested that AR technologies can help develop motor skills and coordination [64] by requiring children to move their bodies and manipulate virtual objects, which promotes "active learning" [74]. It is important to keep in mind, however, that the use of XR technologies may also influence and/or increase children's addiction to technologies, which highlights the importance of these experiences being focused and supervised.

Combining Interactive Narratives and AR, this game was able to engage children through the experience and keep their attention while disseminating knowledge.

2.5 Integrating Narratives, AR, and Location: Discussion of the research gap

While linear AR experiences have been effective in educational settings, they often suffer from limited replayability, which reduces long-term engagement, particularly in environmental education. Once the narrative is completed, there is little incentive to return, limiting the depth of connection to the content. In contrast, nonlinear narratives allow players to influence the story's direction, encouraging multiple playthroughs and fostering a deeper connection to the material. This approach is particularly valuable for environmental education, where repeated interaction with nature can enhance learning and engagement.

A review of recent literature suggests that relatively little research has explored how nonlinear narratives can be effectively implemented in real-world outdoor AR environments. Most of the existing work has focused on controlled, indoor, or screen-based contexts, leaving a gap in our understanding of how interactive storytelling can function dynamically in outdoor, Location-Based settings, particularly those involving children and natural heritage education.

This research aims to fill that gap by exploring how nonlinear AR narratives can enhance environmental education and promote ongoing engagement with nature. To do this, we designed *Eco Detectives*, a game that immerses children in a branching narrative while encouraging visits to a local natural park. This project is being developed with the support of **Parque Ecológico do Funchal**, ensuring that the game is closely integrated with the local environment.

3 Eco Detectives: Design Process and Implementation

This chapter details the complete design and development process of our prototype, "Eco Detectives," which serves as the primary research instrument for investigating how AR, non-linear narratives, and location-based experiences affect children's engagement with environmental education. As the tangible artifact, this prototype enabled data collection that directly informs our research questions. The chapter begins by establishing the research-through-design methodology that guided the project, followed by an overview of the collaboration context with Parque Ecológico do Funchal. It documents the prototyping phases, including both low-fidelity and high-fidelity versions, the technology selection process, narrative structure design, and user experience considerations. It also provides comprehensive documentation of the narrative design, AR interactions, location-based systems, user experience and all visual and technical implementation.

3.1 Methodology

As stated previously, Interactive Narratives have shown great success in engaging children with topics they might otherwise find uninteresting. Simultaneously, Augmented Reality (AR) and Location-Based Experiences can significantly increase immersion within a natural environment. By using a video game as the medium, these three elements can be combined to create a powerful experience. This approach not only allows for a unique test of this specific combination's potential but also results in a tangible artifact that can be used for future applications. For this reason and for the sake of answering our research questions, this project adopted a research-through-design approach [79]. Research-through-design operates through iterative cycles where the act of designing generates knowledge that cannot be obtained through traditional research methods alone. In this approach, the designer alternates between creating an artifact, reflecting on its problems, researching, and remaking it to implement improvements, with each iteration produceing insights that inform the next cycle, with the artifact itself serving as both the research instrument and the embodiment of accumulated knowledge. This methodology is particularly valuable when investigating novel combinations of technologies or interactions, such as the above mentioned, as it reveals practical constraints, user behaviors, and design principles that emerge only through implementation and testing in real-world contexts.

The prototype, "Eco Detectives", served as a tangible variable, allowing us to test its effectiveness in a controlled, yet realistic, setting and leaving behind an artifact with immediate outside implementations. Following a previous iteration, the prototype "Eco Detectives" started development from the ground up. The design process began with low-fidelity prototypes to quickly test core concepts, which then evolved into a high-fidelity version. This final prototype was then subjected to user tests to evaluate its effectiveness in engaging children aged 9 to 13. The user tests involved a combination of gameplay observation and semi-structured interviews. These interviews were crucial for understanding how the experience engaged the children and allowed us to gather specific feedback on the game's effectiveness in specific topics. The data collected from these tests directly informed our understanding of the prototype's impact and provided a clear, data-driven basis for our conclusions.

3.2 Context of the Narrative Experience

Parque Ecológico do Funchal, managed by the Funchal's Municipal Council, is far more than a simple public park. Established in 1994, its primary mission is to promote nature conservation and environmental education. The park itself, aproximately 10km^2 of the Madeira Natural Park, holds immense ecological importance as a protected area and a key part of the European-wide Natura 2000 network. It is a vital habitat for endemic flora and fauna, including the critically endangered Zino's Petrel, a species whose conservation efforts are central to the park's mission. The park also houses many other endemic and migratory species, such as, the frutivourous bat, the Madeiran firecrest and the star mushroom.

Figure. 2: Collage of the Park and some of it's species. Images retrieved from Parque Ecológico do Funchal's Facebook page

The team behind the park's management was very supportive of this project, as it provides a modern tool to engage a crucial audience, children and young teens, on topics that are often difficult to make engaging or exciting. By blending technology with the natural environment, the aim of our project is to serve as a new platform for promoting biodiversity and conservation (See Section C). This not only reinforces the park's status as a leader in environmental education but also helps justify and attract resources for ongoing conservation efforts.

For the users, the game transforms a potentially passive visit into an active, immersive learning experience. Instead of simply reading informational signs, children become "Eco Detectives" on a mission, creating a personal and memorable connection to the park's ecosystem. The game's design encourages physical activity, problem-solving, and curiosity. Ultimately, the project's goal is to turn a casual park outing into a fun, educational adventure that fosters a deeper, lasting appreciation for the environment and the importance of conservation, directly supporting the park's core values.

3.3 First Iteration: Mistério do Parque Ecológico

During our MDMI class of "Interactive Narratives I", as a group project we were tasked with creating a piece of interactive media for children aged 9 to 13. The project's goal was to teach them about the species residing in Funchal Ecological Park in an engaging and entertaining way. Our solution was a location-based mobile game, titled "Mistério do Parque Ecológico" where players become detectives, solving the "murder" of Azul, a Zino's petrel (See Fig.3- B). Using a map (See Fig.3- C) players navigate the park with Azul's wife, Avisa, to find QR codes that, when scanned (See Fig.3- D), introduce them to different animal characters that give them clues on the perpetrator (See Fig.3- E).

After collecting clues from all six characters, players enter a final scene to deduce the culprit. The murderer is revealed to be Bolinhas the cat, who committed the crime after being abandoned by his owners (See Fig.3- F). The game ends with a cautionary message about the responsibility of pet ownership. In a final twist, it's revealed that Azul was not murdered but had simply fainted from shock. The game was designed as a visual novel, with comic book-style visuals featuring static character sprites and speech bubbles. A large "continue" button advanced the story, while other icons allowed players to switch between a map and a notebook that contained information about the animals and clues.

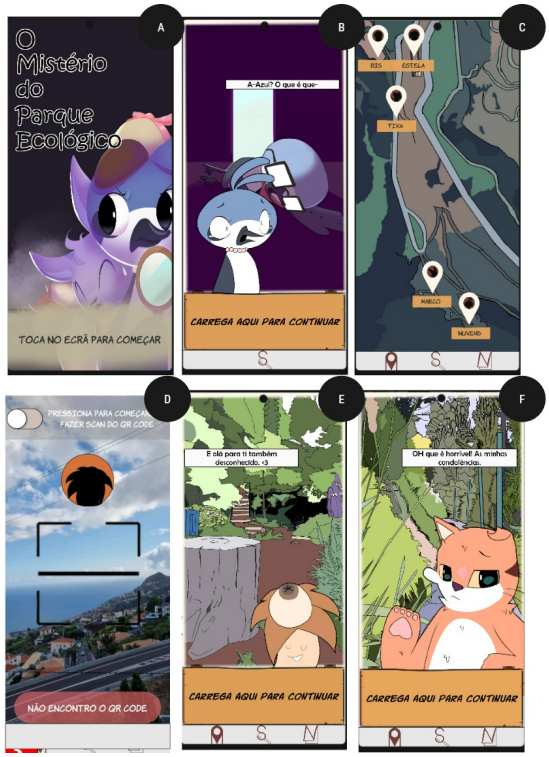

Figure. 3: Mistério do Parque Ecológico GameFlow - A. Title Screen; B. Azul's Death Discovery; C. Map; D. Camera Scan E. Character interaction; F. Culprit Discovery

The game's cast included Azul and Avisa, two Zino's petrels, Bis the Madeiran firecrest, Stella the star mushroom, Marco the bat, Tixa the Madeiran lizard, Bolinhas the cat, and Clouds.

The project was praised for its potential to be a fun and interactive way to educate children about local species and the threats they face from humans. It also had the potential to encourage visits to the park, fostering a connection between young people and nature and potentially inspiring future interest in ecological conservation.

However, after informal testing and logistical discussions with Funchal's Ecological Park, it was clear that the prototype's pacing and design needed to be adjusted to better fit the setting. The stakeholders main concerns were that the game was too long and unsafe for the target audience. The game's route was too long, requiring about an hour of walking through areas that were difficult to supervise and had dense tree cover, resulting in a shift to a smaller, more open location to ensure the children's safety. Additionally, the game's text was too extensive, with a reading time of 30-45 minutes. Combined with the walking, this made the total experience almost two hours long, which was deemed excessive for the target age group.

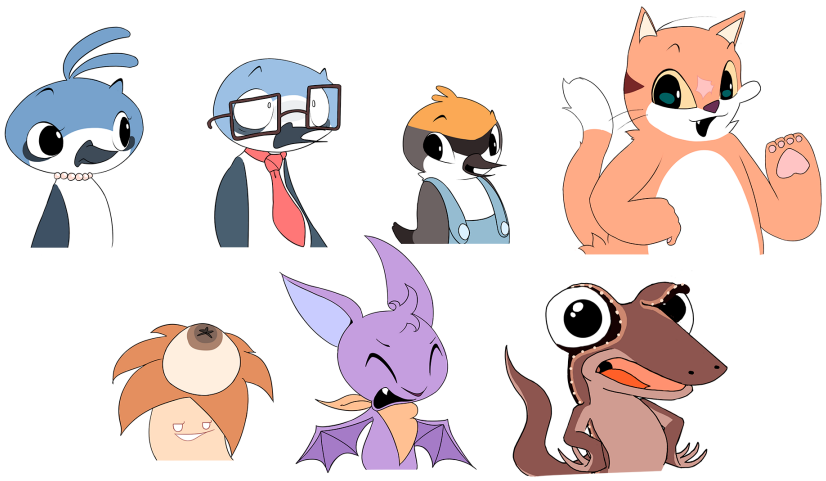

Figure. 4: The original character designs of the cast of the first iteration of Mistério do Parque Ecológico

A significant concern was that the text-based nature of the game created a disconnect from the natural environment. With users focused on their phones' screens, the experience felt like a run-through rather than an interactive exploration of the park's surroundings. It became clear that a solution was needed that could blend the digital story with the physical world, encouraging children to look at nature and engage with their surroundings, while not having the experience or the users disrupt the natural environment. Finally, the character designs for characters like Avisa, Azul, and Marco were deemed too fantastical and not scientifically accurate enough, and accessories like glasses and necklaces were seen as distracting from the naturalistic feel of the characters. The park also requested that more species and specific traits of the park be included and represented in future versions to better represent the park's biodiversity. To address these suggestions without sacrificing educational content or overextending the experience, a new structure was needed to streamline the experience. Not only that but new mechanics were needed to present some information so as to not fully disconnect users from nature.

3.4 Eco Detectives: Solution and Redevelopment

Based on the challenges identified in the first iteration, a systematic return to the literature was necessary to identify evidence-based solutions. This reflective phase examined how other researchers had addressed similar challenges in location-based games, and interactive narratives for children. The solution that emerged from this research was a powerful combination of Augmented Reality (AR), location-based experiences and a non-linear interactive narrative. This new structure directly

addressed the prototype's shortcomings and aligned the game more closely with the park's and the project's educational goals.

As mentioned previously, the original prototype suffered from a long, text-heavy narrative which risked causing reading burnout and fatigue, however, simply cutting the text wasn't a viable solution, as the need to add new content would have just led to a cycle of replacing deleted paragraphs. This is where a non-linear narrative solved this by allowing us to shorten any single playthrough while leveraging a greater variety of content. Using a non-linear narrative, based on player choice and interaction, we would be able to present different characters and stories in separate playthroughs, which ensures that players are not overwhelmed in a single session while also increasing replayability.

With AR-based gameplay, we were able to introduce new mechanics to move beyond the text-heavy visual novel format. Instead of just reading about the park, users now actively interact with objects that reference the park's characteristics. By scanning markers (replacing the previous QR code system), they trigger digital content. This directly combats the "run-through" feeling and lets children experience the park's visuals even while looking at their screens, effectively engaging them with the real world around them. This transition effectively anchored the digital narrative to the physical landscape, ensuring that the technology acted as a lens for observing the park rather than a distraction from it.

A new location was also chosen with the help of the Funchal Ecological Park, who had previously tested it as a safe space for children to undergo such an experience.

3.4.1 Low Fidelity Prototype

Before prototyping, the design process began with simple digital sketches. These early sketches served to visualize initial UI concepts, map out user flows, and explore potential interaction ideas. This sketching phase was essential for communicating the vision of the project (See Fig.5).

After the initial early concept phase, to quickly iterate on ideas, a low-fidelity prototype was created using Figma as the development platform. This allowed us to get an in-depth understanding of the basic layout and structure of the mobile app designed in order to take children on a walk around the park while also enjoying the mystery presented by the narrative.

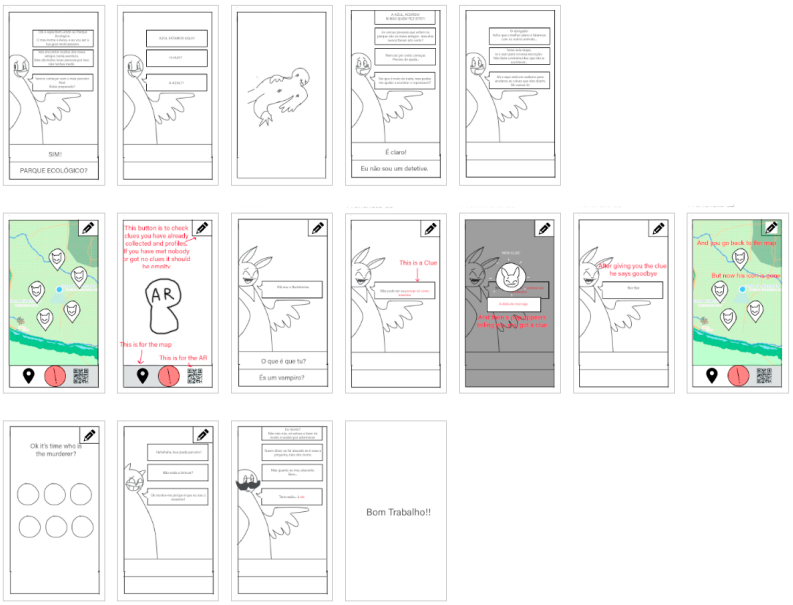

Figure. 5: Sketches of initial concepts for the "Eco Detectives" project

It was originally created using simple wireframes, using basic monochrome shapes, placeholder objects, and textures for all desired features and mechanics, such as the narrative scenes, UI map and AR ideas. This prototype would then be given sketch versions of UI elements and character sprites to test things such as size and color combinations of UI elements (See Fig.6).

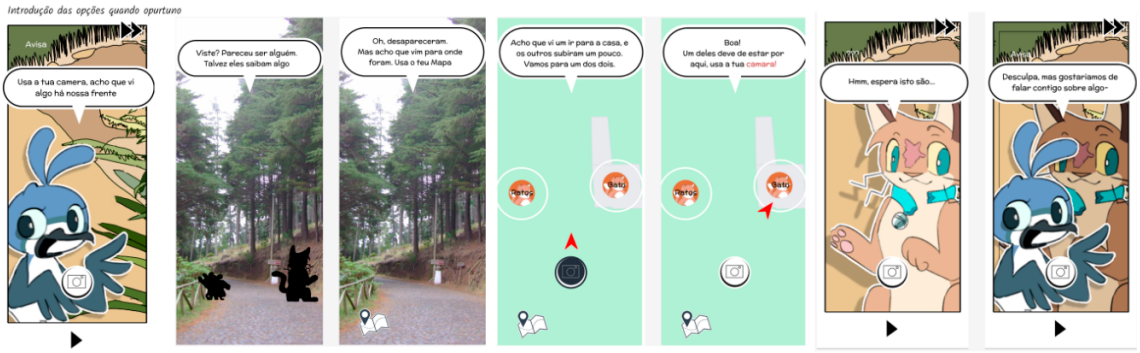

Figure. 6: Screenshots of the low fidelity prototype's UI and AR features

AR features underwent several iterations during the early stages of the project. Initially, users could explore the natural world entirely through their smartphone's camera, with characters and other objects appearing in the environment using the Google Maps API, which determined where the characters would spawn. However, this approach was quickly abandoned due to internet connectivity issues in the park and technical complexity, which interfered with the Google Maps func-

tionality. As a result, later iterations of the AR interactions switched to marker-based technologies to eliminate the reliance on wireless connections.

The final version of the low fidelity prototype ended up including all narrative branches and features that would be included in the final version of the high fidelity prototype already organized (See Fig.7).

Figure. 7: Zoomed-out view of the full application flow, showcasing all screens developed for the low-fidelity prototype.

3.4.2 High Fidelity Prototype

With most features being outlined thanks to the low-fidelity prototype, the high-fidelity prototype of "Eco Detectives" entered its full developmental phase. This prototype serves as a comprehensive test environment for evaluating the game's core features, including its visual style, User Interface (UI), interactive narrative, and Augmented Reality (AR) segments.

The primary purpose of the high-fidelity prototype was to allow us in-depth testing for the study, assessing the integration of interactive elements, the flow between story and exploration sections, and the effectiveness of its educational features.

3.5 Tech Review

Early on in the development of the smartphone application, it was important to choose an engine that could combine visual novel elements with AR mechanics while making sure that said engine would allow efficient implementation and not harm the final prototype's performance. Although options like Ren'py or the Unreal Engine have shown results in both areas, Unity stood out due to its versatility and extensive community.

For those not particularly adept in coding, Unity's[1] visual editor allows users to drag and drop assets, allowing for intuitive scene design and UI implementation. Not only that, but it also supports C Sharp, which is regarded as one of the most user-friendly languages for scripting.

Ren'py might have been a better platform for a sole visual novel experience; it's lack of AR capabilities makes it undesirable in this project, while on the other hand, Unity can create games that use both visual novel mechanics and AR features all within the same environment.

Additionally, although the Unreal Engine was released before it, due to its extensive library of documentation, forums, tutorials, examples, plug-ins, and varied asset store, Unity is a preferable tool for beginners.

Unity has multiple plugins that would allow for robust AR implementation on both Android and iOS smart devices, such as AR Foundation and AR Core, the chosen plugin for this project. It also supports plugins for branching narrative dialogue systems, such as YarnSpinner[2], which is widely used in text-based projects, such as Night in the Woods [19] a game with an extensive dialogue system.

In conclusion, due to Unity's combination of AR and visual novel plugins, as well as its user-friendly systems and wide documentation, this platform was chosen for the game's development. Comparatively, other platforms like Unreal Engine or Ren'py would have needed much harder implementation of both mechanics due to, in some cases, needing potential hard coding of previously stated features.

3.6 Narrative

As mentioned previously, to improve on the previous prototype, the narrative was changed in order to tackle issues regarding length and replay value while also adding new educational content to the experience.

The improved narrative employs a "concentric" type of Interactive Narrative structure, which allows for users to experience a narrative with the same beginning and ending while also giving them the opportunity to choose different outcomes in the middle that will in some way, affect the ending, increasing a narrative's replay value without the need to create multiple endings and streamlining development. The narrative now supports a cast of ten characters, split between two

[1] unity.com
[2] https://www.yarnspinner.dev/

stories focused on the abandonment of domestic animals near protected natural zones and the continuous growth of pests, such as rats, due to the inappropriate disposal of trash within the park. Ten characters were then divided into groups of six (with some repetition), with players only needing to find three of them to progress through the story's final section and conclusion (See Fig.8").

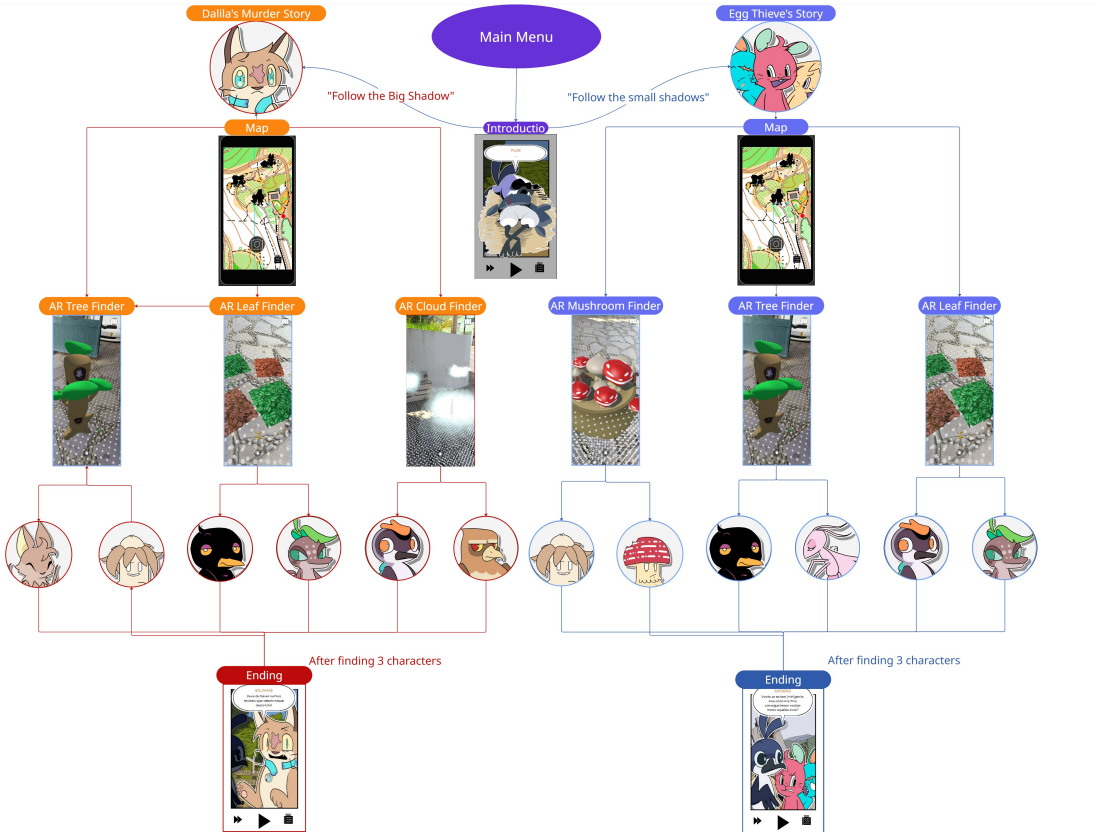

Figure. 8: Eco Detectives Narrative Structure

The narrative begins with a shearwater named Pilar, who introduces herself as one of the ecological park's guides. She explains to the users that to begin their scheduled trail, they must first find Dalila, a Zino's petrel, who is currently taking care of Pilar's egg, but although she is found, Dalila is unconscious on the ground, with Pilar's egg being nowhere in sight.

Believing that her friend was murdered and her egg was stolen, Pilar asks the user to help her find the truth behind both crimes.

The users are then presented with shadowy silhouettes near the scene, one large and a few small, who may know something, leading to a branching choice where players are asked which to

follow, essentially deciding which story path they will explore; one, Dalila's Murder story, focusing on Dalila's murder, and the other, Egg Thieves story, which focuses on the stolen eggs.

Following a large shadow, users enter Dalila's Murder story, users find a cat, who found Pilar's egg but provides no other information regarding who stole it or what happened to Dalila herself. Following the smaller shadows, users will bump into three rats who, after a bit of back and forth, find out that Dalila is not dead and only unconscious but say they have no idea of why the eggs have gone missing. In both scenes, users must tell Pilar which treat she should give to the corresponding animal in order to calm them down, which is a recurring mechanic players will need to interact with and a very important clue that will become relevant in the game's climax. With no information on the crime of the respective story, players are led to a walk around the park with the purpose of finding witnesses or potential leads to the murder or the robbery.

Each of the three animals that users may find gives them a descriptive clue regarding themselves and the culprit's body type, abilities, and diet. Upon finding all of them, a final showdown between the found animals will commence.

In the Dalila's Murder story, the correct choice for the mastermind is the cat, due to his size, carnivorous habits, and the teeth shaped wound on the victim. After an appearance from a very alive Dalila, who had only fainted from shock, we learn that the motive for this sudden crime was due to the cat's fasting after being abandoned in the surrounding area by its owner.

In the Egg Thieves story, it is found that due to their diet, ability to dig and carry objects, and their large population, the only ones who could have committed the crimes were the rats. Their growth in population is also brought into question, where it is then revealed that due to humans leaving trash around during their walks through the park, many mice have found food, and therefore the energy, to increase their numbers.

Both stories end with the characters reflecting on the fact that a few humans' actions can lead to these events and ask users to not only avoid similar behaviors but also be active in helping such events to be remedied, either by informing local staff of similar events or picking up garbage left behind when safe to do so. After a final goodbye and a request for the users' return to figure out the truth behind the story not picked, the narrative reaches its conclusion.

With this narrative, our objective is to bring up issues regarding the upkeep of the park, as well as low effort actions that users need to take to make this ecosystem safe for the fauna and

flora that live there, as well as hopefully rooting natural values in children, so they may develop as they age.

3.7 User Experience

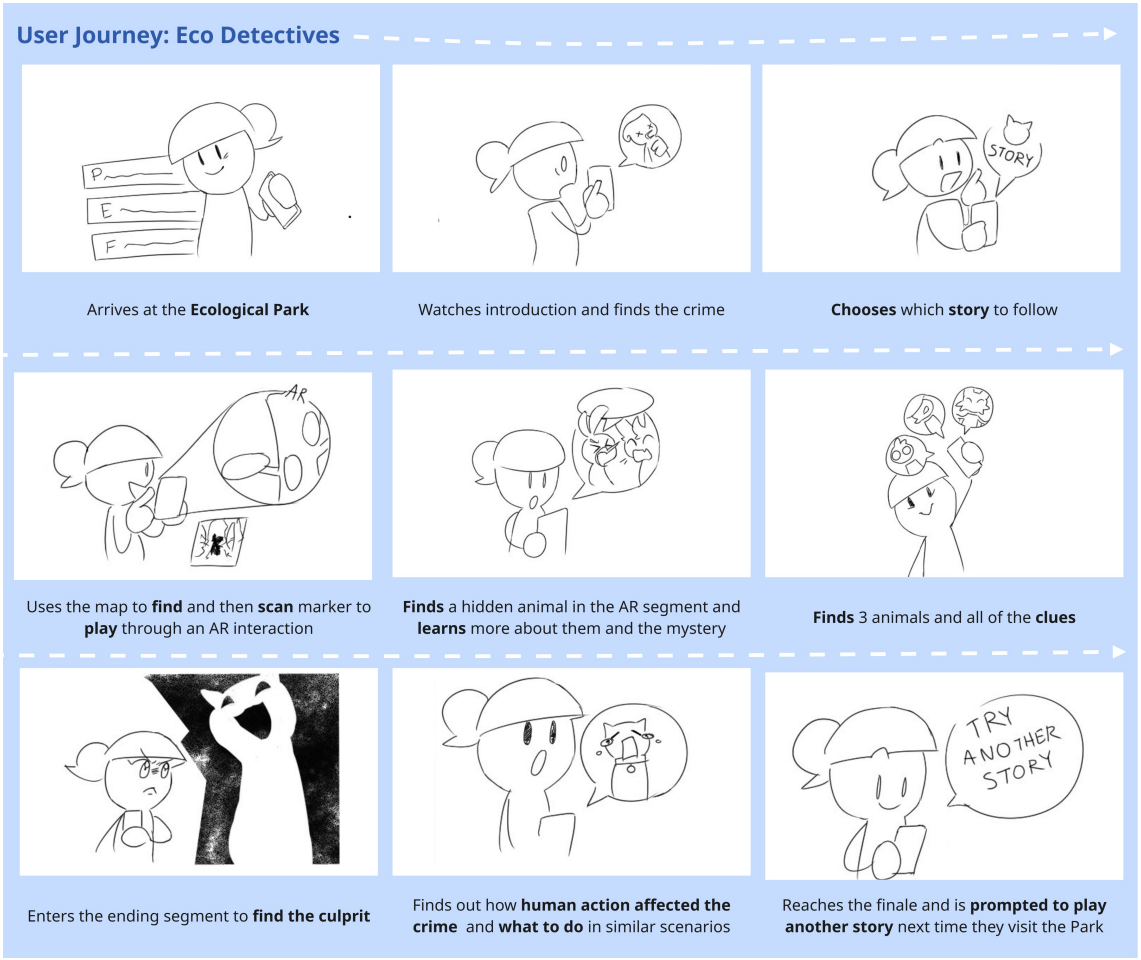

Figure. 9: User Journey of Eco Detectives

The user experience begins at Funchal's Ecological Park, where the players, aged between 9-13 years old, takes out their phones and begin the application "Eco Detectives" which opens with the main menu, where a click on the screen proceeds to the introduction (See Fig.10 - A), a tutorial section where players are shown how to interact with the UI and the game's story mechanics, like making choices (See Fig.10 - B and C). Players can advance through the story by clicking a "Continue" button, and after the introduction, players face a branching choice, where they can either "follow the big creature" or "follow small creatures" which determines whether they will enter Dalila's Murder story or the Egg Thieves story respectively. After completing the initial

story scene, players are taken to a map scene specific to their chosen story that displays the area of the ecological park they will explore. This map displays the location of image markers and includes the patterns found on the marker for clarity (See Fig.10 - E). Clicking the camera button on the map screen transitions to the camera scene, where players can scan image markers tied to the current story (See Fig.10 - F). The game checks the marker ID and loads the specific AR interaction scene. If a scanned marker is not part of the current story's path, it will not be recognized, and players will be prompted to scan the correct marker.

Once an AR interaction is loaded, players are prompted to play an AR mini-game (See Fig.10 - G). The goal is to find a specific animal hidden within the 3D AR model. There are two possible animals to find in each mini-game. Once one is found, players progress to a character story scene where they receive clues about the current mystery.

After the previous scene, the game returns to the map. Players must find and scan the other two markers and repeat the process. Once all three markers are found, the game automatically loads the Ending scene when the player returns to the map. In this scene, the specific characters discovered during the AR interactions appear. Here, players must decide who the thief is. If they choose correctly, they are presented with a series of choices to select the correct reasons for their choice. Incorrect choices will cause the game to loop back to the decision point. After making the correct choices, the game proceeds to the final ending, followed by the credits. Throughout the story scenes, a notebook button is available. This button opens a list-view scene that provides personal and scientific information about the animal characters, such as their names, abilities, likes, dislikes, and habitats. Pressing the same button again returns the player to the story scene via a smooth visual transition (See Fig.10 - C).

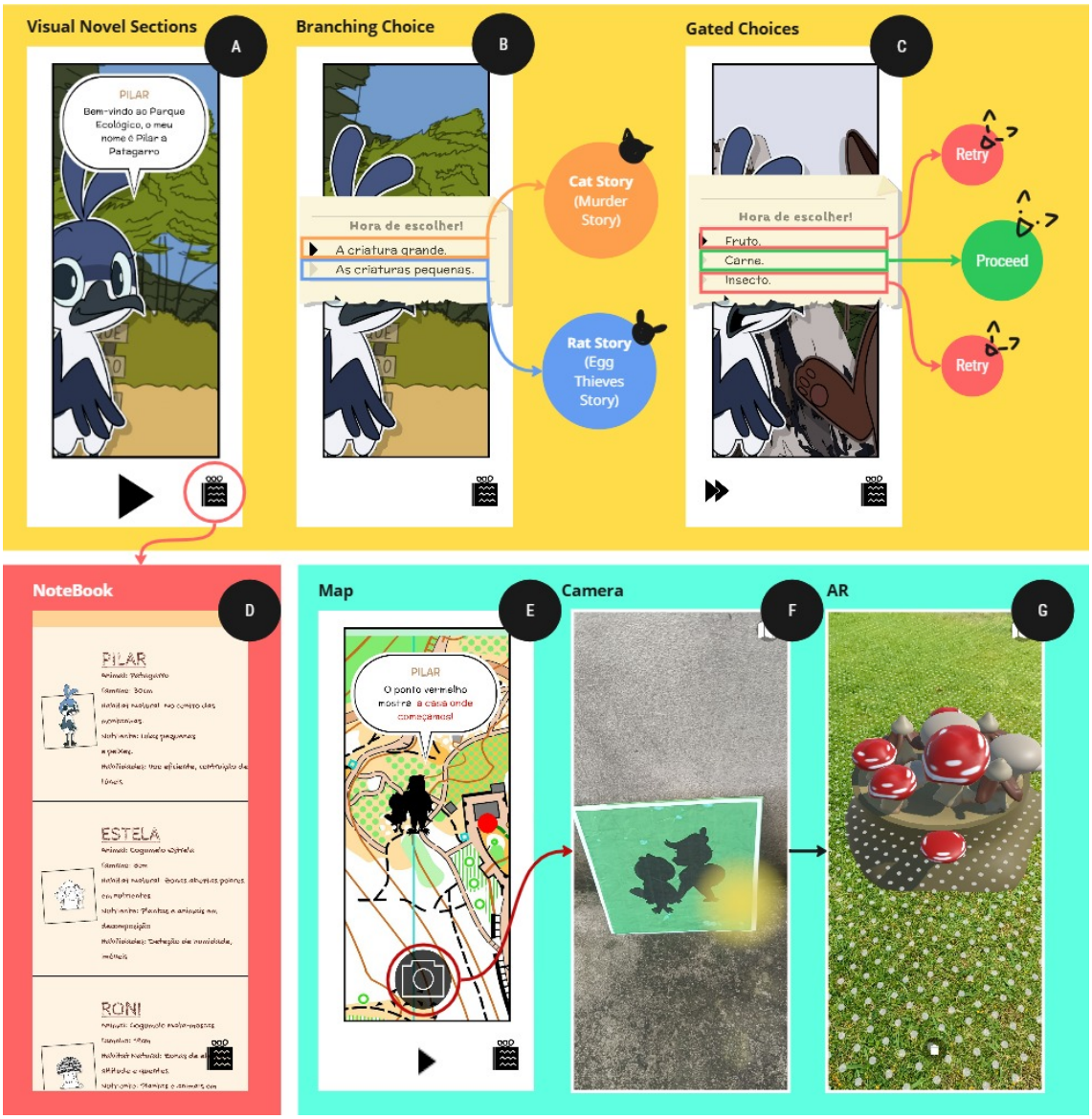

Figure. 10: User Interface of Eco Detectives system's - A. Introduction/Visual Novel scene UI; B. Branching Choice; C. Linear Choice; D. Notebook Feature; E. Map; F. Camera Scan; G. Augumented Reality

3.7.1 Augmented Reality (AR) Design

The AR design in Eco Detectives plays a crucial role in bridging the virtual world of the game with the real-world environment, enhancing the immersive experience for players. This integration encourages young players to engage with both the digital world and their physical surroundings in a seamless and playful manner. The AR segments were crafted to provide an engaging break from the story-based sections of the game while maintaining a strong connection to the real-world Ecological Park and its natural beauty as not to break the connection between nature and the users. In these segments, the players must interact with real-world objects such as trees, leaf piles,

clouds, and mushrooms, which are brought to life through 3D models and animations on their smartphones

The AR objects are deliberately designed with simplicity in mind, featuring bright, flat colors and minimal textures. This decision ensures that the augmented objects do not compete visually with the real-world environment while still being visually striking and easily recognizable for young players. For example, 3D mushrooms might appear as oversized, brightly colored objects with soft, rounded edges, while a tree might be represented as a stylized, blocky figure with exaggerated proportions. Particle effects, such as glowing lights or sparkles, are used sparingly to create magical moments without overwhelming the player.

The AR experience is designed to be playful rather than overly complex. Interactions with the 3D objects are meant to be intuitive and uncomplicated, therefore, no complicated movements were added, allowing players to engage with the environment without the need for complex instructions. The visual simplicity of these AR elements ensures that the game remains accessible, focusing on discovery and exploration rather than technical challenges.

3.7.2 AR interactions

The game has 4 simple AR mini-games. Each mini-game is linked to a specific type of object in the park—trees, mushrooms, clouds, and leaf piles—and the player must find and interact with these objects to progress the story. Below is a look at each of the AR mini-games:

In the **Cloud Finder** mini-game, (See Fig.11)players are tasked with identifying and tapping on the correct clouds within the game. When players look at each 3D, they will see silhouettes of different objects, and they must discern which looks the most like an animal. The interaction encourages players to carefully observe their environment and adds another layer of exploration to their experience.

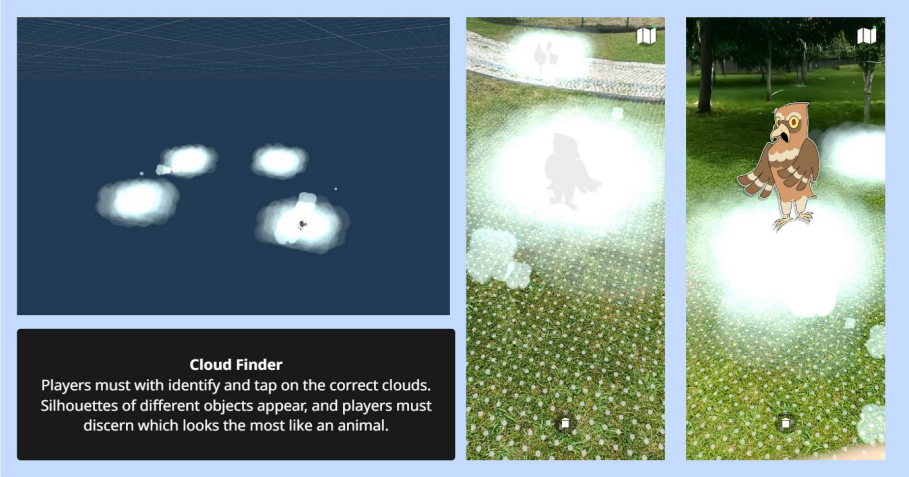

Figure. 11: Unity Editor and Smartphone Gameplay of Cloud Finder AR Mini-game

The **Mushroom Finder** mini-game (See Fig.12)invites players to search for a specific mushroom in the park. Once the player scans the area with their phone, a 3D stump full of mushrooms will appear, brightly colored and stylized. The goal is to tap the correct AR mushrooms, that were designed to have a face, requiring children to move their phones around to locate them. This interaction promotes careful visual awareness, as children need to identify and select the correct mushroom to advance the story.

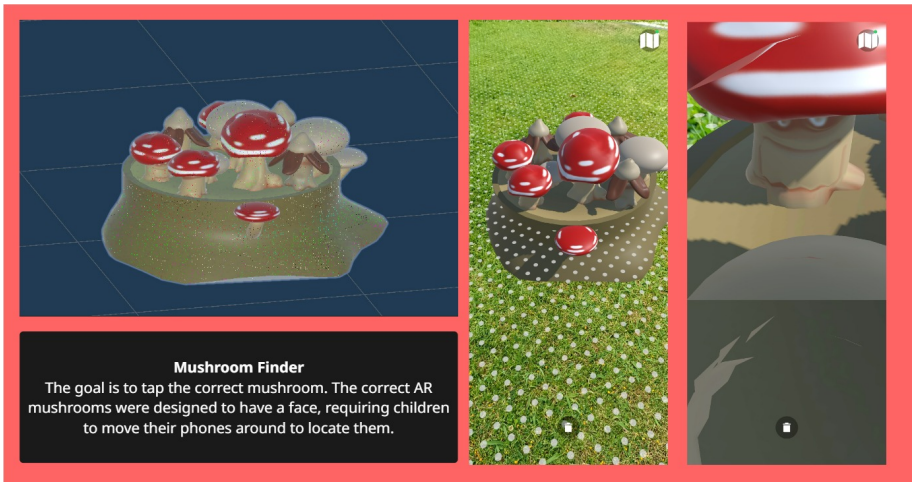

Figure. 12: Unity Editor and Smartphone Gameplay of Mushroom Finder AR Mini-game

In the **Leaf Finder** mini-game (See Fig.13), players are instructed to find the correct leaf pile containing an animal. When scanning the area with their phone, the leaf piles will appear in 3D, each hiding different animals. The AR elements are designed to be a bit more realistic than the

others in order to blend in better with the park's actual foliage, making the interaction feel like a natural extension of the environment.

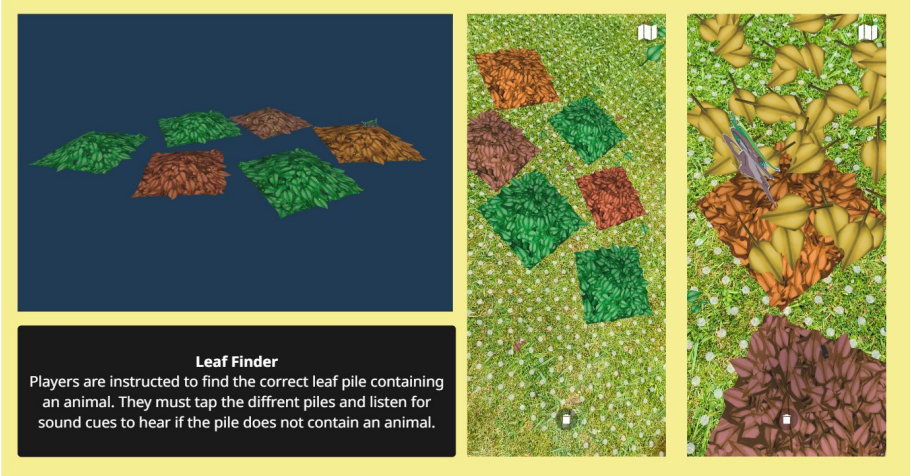

Figure. 13: Unity Editor and Smartphone Gameplay of Leaf Finder AR Mini-game

The **Tree Finder** (See Fig.14 mini-game requires players to locate a tree hole with a hidden animal inside. Players not only must tap on the correct tree to reveal the animal but make sure they listen to audio cues to hear if the tree is empty. Just like the mushroom finder minigame, this minigame asks players to move themselves around the AR object in order to fully interact with it.

Figure. 14: Unity Editor and Smartphone Gameplay of Tree Finder AR Mini-game

3.8 Visual Implementation

This chapter provides a detailed overview of the project's visual design and asset creation. It outlines the specific tools, techniques, and workflows used to develop all visual and interactive assets. The section is organized by asset type, offering a clear and comprehensive account of the art production pipeline.

3.8.1 User Interface (UI) Design

The UI of "Eco Detectives" was designed to maintain the game's visual appeal while also ensuring that it is easy for children to navigate. Drawing inspiration from comic book layouts, the story sections were created to resemble a specific distinct visual style, using outer white edges to mirror the borders of comic book panels. This design helps to visually frame the character sprites, drawing the player's attention to the visuals and dialogue without overwhelming the screen.

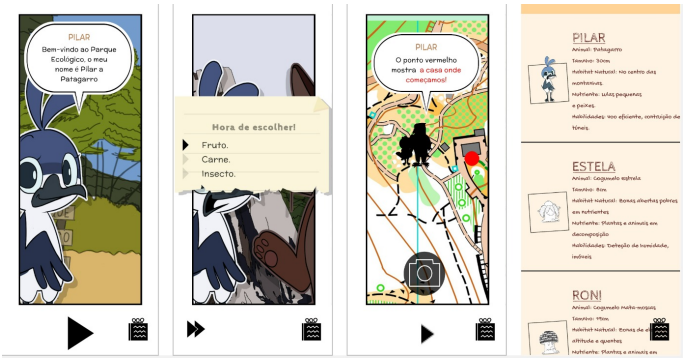

Figure. 15: Screenshots of different scene's showcasing the User Interface(UI)

The narrative dialogue is displayed in speech bubbles, an iconic element of both comic books and manga. This method of presenting dialogue is accessible and familiar to children, making it easy for them to follow the narrative and understand the flow of conversation. The speech bubbles' placement and design are optimized for readability, ensuring that text is legible against the backgrounds. The use of bold, simple typography reinforces the playful and engaging nature of the game, further enhancing its appeal to a younger audience.

3.8.2 Character Design and Animation

The game's characters are primarily drawn from both native species found in the ecological park of Funchal and animals introduced from outside. These characters are designed with an anthropomorphic style, featuring exaggerated proportions, such as large heads, big eyes, and small torsos,

which enhance their cuteness and overall appeal to a young audience. This style of character design is reminiscent of anime aesthetics, with clear influences from both Japanese animation and Western cartoons, due to their popularity among children. The visual emphasis on innocence and playfulness is achieved through large, expressive eyes that convey a wide range of emotions, making it easier for children to relate to the characters and become emotionally invested in their stories.

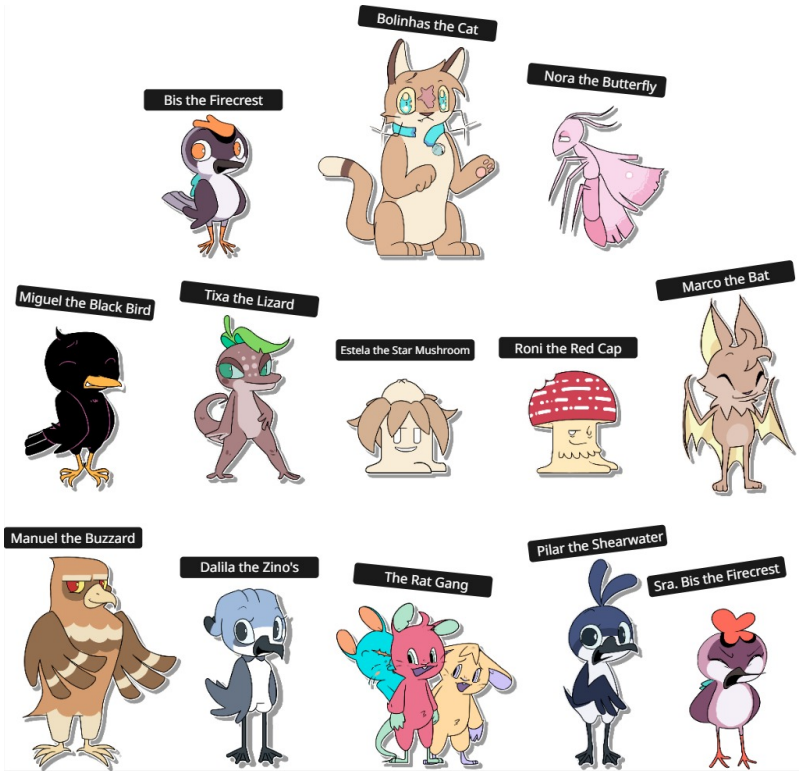

Figure. 16: The full cast of characters of Eco Detectives

The characters' body language and facial expressions further contribute to the lighthearted tone of the game, ensuring that even more serious aspects of the mysteries are presented in a way that is approachable for younger players. This design choice also helps ensure that the characters retain a sense of personality and depth, despite their simplified and stylized forms. All character sprites were originally conceptualized and drawn digitally on Adobe Photoshop. This program was selected for its robust capabilities, particularly its extensive brush engine and layered file structure. The ability to use layers was crucial for efficiency, as it allowed us to create different emotional states and sprite variations by simply toggling layers on and off. To add a layer of liveliness, simple animations for the sprites were created using Unity's in-editor animation feature.

A noticeable change was made from the previous prototype designs based on feedback from the Parque Ecológico do Funchal. The omission of human accessories and a previously seen wild color scheme was implemented to ensure the characters not only better resemble their real-life counterparts but also have meaningful design differences between the animals that should and should not reside in the park. For example, the cat wears a collar, while the mice have more unrealistic colors.

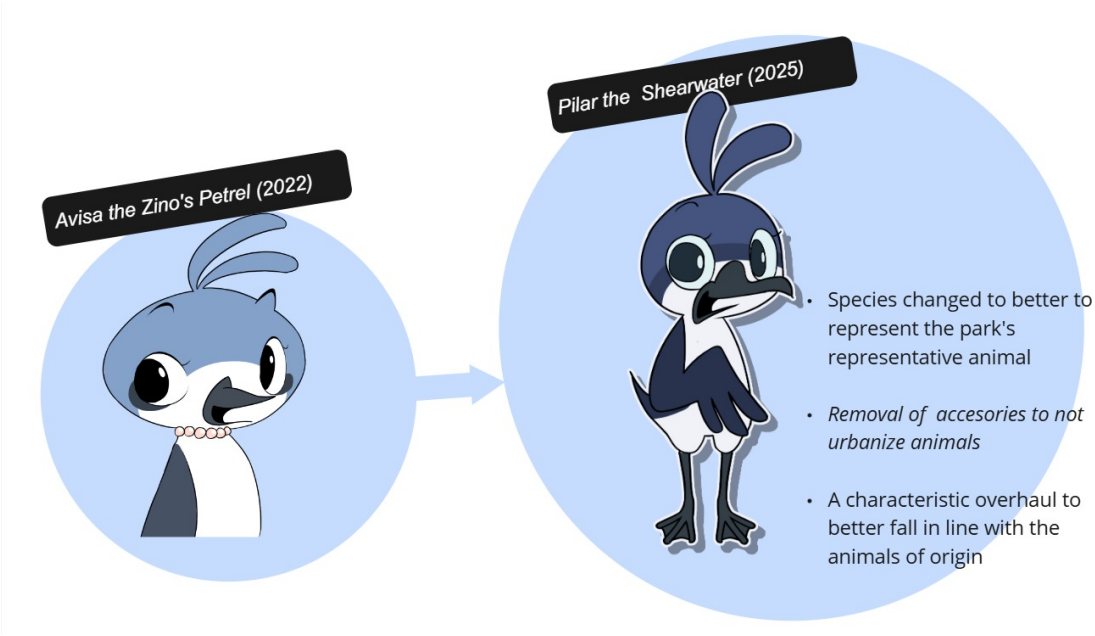

Figure. 17: Eco Detective Character Redesign: Avisa the Zino's Petrel to Pilar the Shearwater

3.8.3 3D Modeling

The 3D objects for the augmented reality (AR) segments were modeled and textured using Blender[3], a free and open-source application. Blender's comprehensive features allowed for the rapid creation and iteration of these objects. A primary technical consideration was performance optimization on mobile devices, particularly for Android. To address this, all 3D objects were intentionally designed with a low polygon count. To visually hide the simplified geometry, a stylized aesthetic was used, employing simple, flat colors with minimal lighting and forced textured shadows.

[3]https://www.blender.org/download/

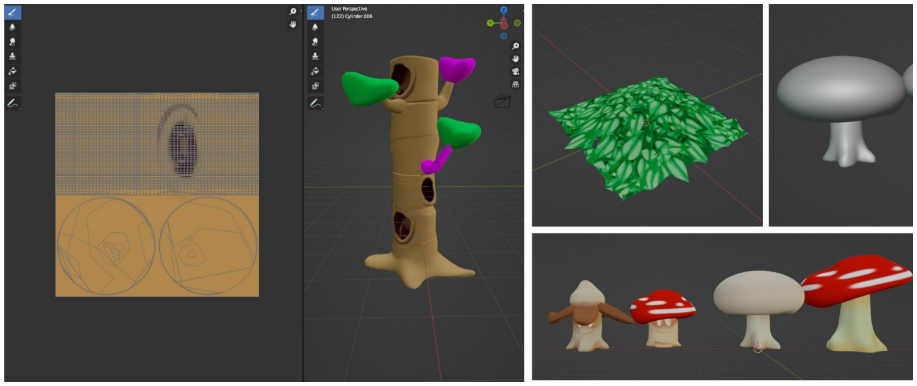

Figure. 18: View of the 3D models within Blender

3.9 Technical Implementation

This chapter details the technical implementation of the project, including the specific software, tools, and workflows used to create all visual and interactive assets. The section is divided by asset type to provide a clear and comprehensive account of the production pipeline.

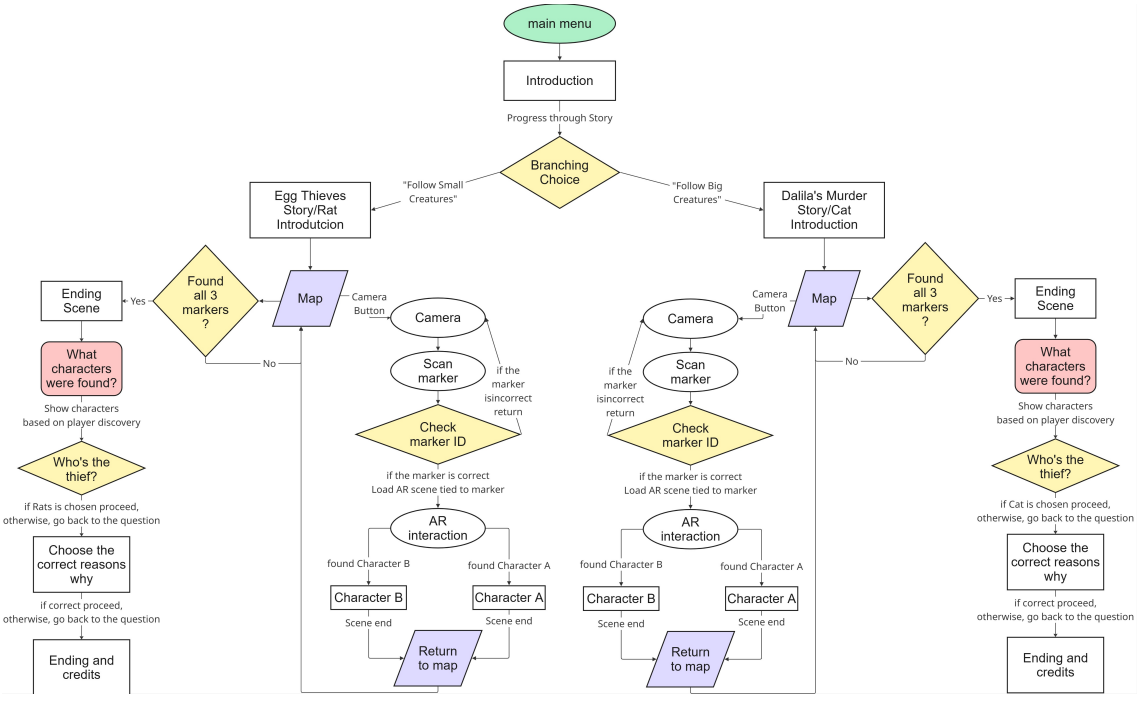

Figure. 19: Eco Detectives Technical Implementation Flow

3.9.1 Narrative and Scripting

The project's interactive narrative was built by integrating the Yarn Spinner dialogue system with the Unity game engine. This combination allowed for the rapid adaptation of a pre-written script

from a document into a functional, interactive experience. A core component of this system was a custom Game Manager script that functioned as an asset trigger holder. This script allowed Yarn Spinner to directly call and manage visual assets from within the dialogue. For example, the Yarn Spinner command «sidePilar GameManager» was used to trigger the display of the sprite for the character Pilar looking sideways. This same method was used to dynamically control the visibility of UI elements, such as buttons, enabling a responsive and context-aware user interface.

Yarn Spinner's single-file structure proved highly effective for organizing all scripts for different scenes within one document, and the jump command was used to navigate between them. This command was also essential for implementing the branching narrative, allowing player choices to lead to different story paths. Although an English version of the game was not a requirement, Yarn Spinner's built-in support for multiple languages would facilitate future localization efforts.

3.9.2 User Interface (UI) Development

The UI's foundational structure was assembled using Unity's visual editor, where it was built upon a modified version of one of the visual novel examples that comes with the Yarn Spinner asset. This enabled the seamless integration of all UI elements, which were originally created in Adobe Illustrator[4] using vector shapes and solid colors. The vector-based approach was a deliberate choice to ensure that all UI elements would maintain visual quality across all screen sizes.

In addition, the UI incorporates simple icons and buttons that allow for intuitive interaction.

3.9.3 Image Marker Scanner Implementation

The augmented reality segments of the game are activated through image tracking, a technology that allows the application to detect and respond to specific visual markers in the real world. This approach was chosen to integrate the game's narrative and exploration themes with a tangible, real-world element, guiding players to discover content in a physical space.

The image markers function similarly to QR codes, but instead of relying on a monochrome pattern, they use a full-color, square illustrated image with a distinct internal mark. These images were imported into Unity's Reference Image Library, where each was assigned a unique ID. When the device's camera, powered by AR Foundation, detects one of these predefined images, it triggers an event-driven system.

[4] https://www.adobe.com/pt/creativecloud.html

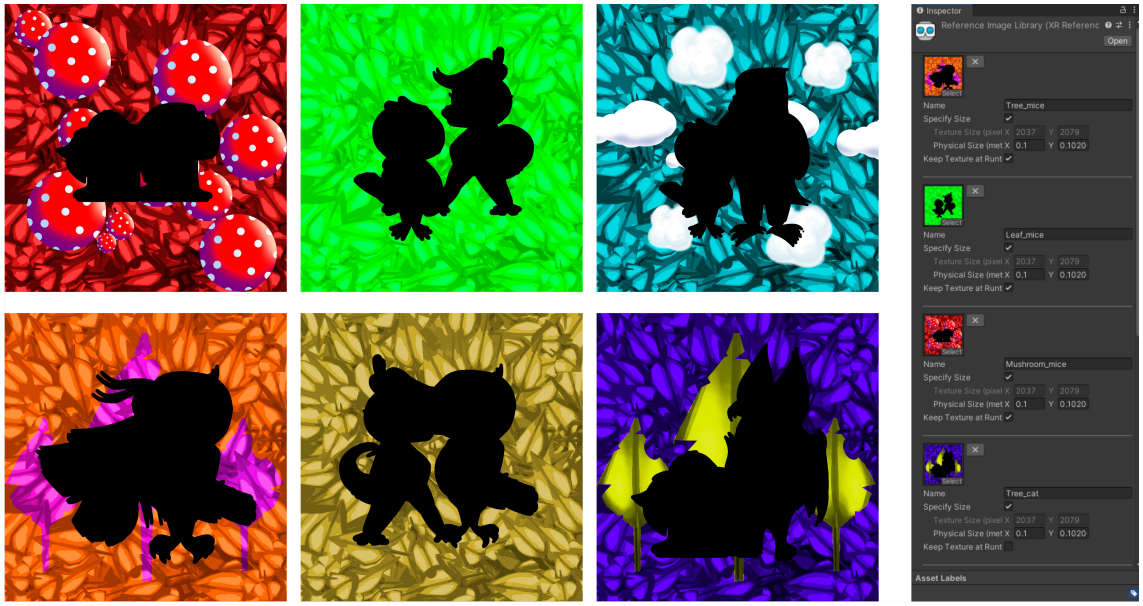

Figure. 20: The various AR image markers and how they are organized on Unity Editor

Upon successful detection, the game uses the image's unique ID to load the corresponding AR scene. For example, if a marker for the "Egg Thieves Story" is detected, the game loads the specific AR scene tied to that branching narrative. The game's branching storylines each have three unique image markers to be found. A conditional logic system ensures players are on the correct path. If a player scans an incorrect marker, a prompt is displayed, instructing them to find the marker with the symbol shown on their in-game map.

For development and testing purposes, a master image tracker was created. This special marker provides access to all AR scenes and mini-games, streamlining the quality assurance.

3.9.4 AR Implementation

The AR segments were built using Unity's AR Foundation and XR Interaction Toolkit[5]. The core of the AR experience was managed by C-sharp script, based on a modified version of an official Unity sample. This script was central to controlling the user interface and object interaction within the AR scene, handling the logic for displaying and hiding the object creation menu and managing the workflow for placing and deleting AR objects.

A key feature of this script is its ability to dynamically change the UI based on the user's focus. It continuously checks if a user is currently focusing on an interactive object. If an object is selected, the "create" button is hidden, and a "delete" button is made visible, providing a clear and

[5]https://docs.unity3d.com/Packages/com.unity.xr.arfoundation@4.1/manual/index.html

```
[SerializeField]
[Tooltip("The behavior to use to spawn objects.")]
ObjectSpawner m_ObjectSpawner;

/// <summary>
/// The behavior to use to spawn objects.
/// </summary>
public ObjectSpawner objectSpawner
{
    get => m_ObjectSpawner;
    set => m_ObjectSpawner = value;
}
```

Figure. 21: Code example of how the system spawns AR objects

context-aware interface for the user to remove unwanted objects. When no object is selected, the "create" button becomes visible again, prompting the user to place a new object. This intelligent UI design streamlines the AR experience and prevents interface clutter.

4 Evaluation of Eco Detectives

After a new version of the prototype was completed, we prepared and conducted a study to answer our main research questions. The study's primary goal was to see how children, ages 9 to 13, interacted with the game, especially its combination of narrative, Augmented Reality (AR) segments, and educational content about the Funchal ecological park.

The study took place within the park. Participants were recruited through direct outreach to guardians and existing network contacts, with a significant number coming from a professional connection leveraged by the supervisor. Because the game's story had no voiceovers, all children needed to be proficient in reading Portuguese, an expected skill for their age and educational level. Due to their age, all participants were required to have legal consent from their guardians, which was obtained through a signed document.

4.1 Protocol

Upon arrival at the park, participants between the ages of 9 and 13 years old received a brief age-appropriate introduction to the game and instructions on how to navigate the smartphone interface. They were told that they are tasked with solving a mystery that involves finding hidden clues scattered throughout the designated area of park (around 7800 m^2).

Children would then start playing the game on the provided smartphones. The game follows a visual novel format, where the player reads and interacts with a branching narrative, making choices that influence the story. After the introductory story section, parts of the story would trigger a map to appear with marked locations that required players to move to them. Upon finding the marked location, they then needed to use their cameras to scan an image to trigger AR segments, where the child can use their phone's camera to view augmented elements overlaid on the park's real-world environment. The AR components included objects that children must interact with to trigger story sections to find clues that help them solve the mystery.

Upon finding all 3 designated marked locations, the children would be asked who they think is the culprit, and the story would then continue to its conclusion once they choose the correct answer, leading to the credits of the game.

After completing the game, participants were invited to take part in a semi-structured interview. Although interviews do not give quantitative results, this method allows for professionals the

opportunity to gather some information and understanding that they would not have otherwise been given with quantitative focused questionnaires [50]. Not only that, but this also avoids the risk of the children misinterpreting the metrics provided.

The interview itself was focused on their experience playing the game, with questions regarding their **general enjoyment, narrative understanding and enjoyment, visuals and characters, AR and map mechanics, and final questions regarding any closing thoughts and interest in revisiting the application** (See Fig.22). It is important to mention that all voice files used for the interview were not shared to anyone but the main researcher, who then deleted them after transcribing them into text.

Categories	Questions
General Enjoyment	What did you think of the game?
	Were you able to complete the game?
	What did you like most about the game?
	Did you think the game was too long?
Narrative Understanding and Enjoyment	What did you think about the story?
	Did you follow the story about the rats or the cat?
	What was the message of the story
	What should you do if you find yourself in a situation where (STORY SPECIFIC)
	You find a pet in a protected natural area like the park?
	You find garbage in a protected natural area like the park?
	Was the text easy to understand?
	Would you have prefered the text to be of a diffrent lenght?
	Would you prefer if the characters had voices?
	Did you learn anything new about Funchal´s ecological park and nature in general?
Visuals and characters	What did you think of the graphics and drawings in the game?
	Did you like the characters?
	Who was you favorite character?
	Were the any characters you didn't like?
Map and AR	What did you think of the search for the images with a map of the park?
	What did you think of the moments when you used your cell phone camera?
	Was there anything you liked most about those moments with your phone's camera?
	Were these moments with the cell phone camera intuitive?
	Was there anything that confused you or didn't work?
	Did you need help from someone?
	Did you find that these moments with the camera and map complement the story well?
	Would you rather play with or without these camera moments?
	Did you find these moments distracting from nature?
	Did you think these moments helped you learn something?
Final questions	Have you visited Parque Ecológico do Funchal before your visit?
	Did you know about this type of problem?
	If you could change something about the app, what would it be?
	Would you go back to the park with this app?
	Would you recommend this app to a friend or family member?
	Would you like to use this type of application to learn more about similar topics?

Figure. 22: Interview questions

4.1.1 Data Collection

All data collection methods included direct observation of player behavior during gameplay and participant feedback through interviews. Each participant was assigned a unique identification code to ensure anonymity and facilitate data organization. The primary research focus was on the user experience, engagement with the game's narrative and AR elements, and the educational value derived from interaction with the park's environment. Interview results were analyzed and grouped into main themes to identify common patterns and insights across participants.

4.2 Participants

The study was performed in three different sessions, based on participant's availability and age range. The study involved 13 participants aged 9 to 13.

Session 1 consisted of three 12-year-old girls, **Session 2** consisted of one 9-year-old girl and one 9-year-old boy, and **Session 3** consisted of four boys and four girls between the ages of 12 and 13 years old. In Session 1, there were two participants who were family, and in Session 3, participants were acquaintances due to being classmates.

4.3 Results from Observations

This section is based on the notes and observations made by the researchers observing the study. In Sessions 1 and 2, while playing, the participants were visibly unengaged during the introduction to the game, later commenting that they found it somewhat lengthy, expressing a desire to move directly to the interactive AR section. Once the AR features were introduced, they became very engaged in searching for images linked to the story.

Session 3 seemed to be somewhat engaged going through the introduction, but like the other sessions, did become more visually engaged when going through the AR sections. During Sessions 1 and 2, all participants were given an individual phone to use to play the game. However, after the first interactions in both sessions, individuals got together and enjoyed playing the game with each other, even though multiplayer interaction was not the primary goal of this project. To get a better view of how solo play would affect users, in Session 3, it was decided that each participant would begin the experience at different times. However, just like Sessions 1 and 2, these participants also got together to play the game 23. It is important to say that each player still played through the

game on their own smartphone, even when they grouped together, which did lead some to get different results during the whole experience.

Figure. 23: User's using the Eco Detectives in a group

Nine players went through the cat story, while only four went through the mice story.

After the first narrative scene with an animal, younger participants from Sessions 1 and 2 took advantage of the ability to make as many mistakes as they wanted, due to the lack of a penalty system. They often chose different options and compared them with each other to figure out the correct one, with the older participants from Session 3 being more interested in choosing the correct option on their first try, boasting about it with other participants that were nearby. Not only that, but in all sessions, many participants began to speed read or skip through the text after the introduction, which was noticeable due to their pace while pressing the continue button. Most of the participants didn't use the notebook feature and, therefore, did not read the scientific information about the animals. A few of them did find it, but they were more interested in the other characters they hadn't encountered, which did seem to excite them for future playthroughs.

While exploring, some players encountered a map error where characters sometimes failed to disappear after being found, which led to some small temporary confusion regarding where to go next, while others had issues reading a specific AR image marker, which seemed to have been an issue based on the specific smartphone being used.

4.4 Interview Results

This section is based on the interviews and observations made during said interviews by researchers. All participants were given a random identifier that started with the number S and their session

number, followed by another number, this time their participant number, and two random letters, for example, S11GA, meaning session 1, participant 1, GA. This was done so as to not divulge their identities, and they will be referred to as such when cited.

4.4.1 General Enjoyment:

All participants across all sessions consistently expressed high levels of enjoyment. Common descriptors for the game included "interesting," "fun," "creative," and "very good." Many highlighted the active nature of the game, enjoying "walking through the trails" and the excitement of "finding images" at various locations. The AR mini-games were almost universally praised, frequently cited as the most enjoyable part of the overall experience. Participants appreciated the novelty of interacting with digital elements overlaid on the real environment.

Regarding game length, all participants found it "not too long" or "perfectly balanced," despite the average playtime being approximately one hour. However, some participants, specifically the younger ones, did comment that the dialogue sections felt lengthy.

As mentioned before, significant and recurrent observation was the unexpected, yet highly appreciated, social aspect. Several participants explicitly enjoyed playing "with other people," even though the game was designed for individual use. They noted it "facilitated communication with other people" and expressed satisfaction in "doing it in a group." Participant S11LU (12-year-old) curiously stated, "I know it's an individual game, but I liked doing it as a group".

The participants were enthusiastic due to the narrative twist involving "the dead Dalila," which significantly contributed to their engagement. One participant of Session 3 showed exceptional enthusiasm, running actively through the park to find all of the hidden markers, and immediately expressing a desire to play the other story path after completing their chosen one. This indicated strong engagement and potential for replayability.

4.4.2 Narrative Enjoyment and Understanding:

The story was generally well-received. All participants enjoyed the mystery element, particularly discovering the culprit and the interactions where the character Pilar questioned the animals. A total of 9 participants, all of Sessions 1 and 2 and some from Session 3, chose to follow Dalila's Murder story (Cat Story), with only four exceptions from Session 3.

Message comprehension varied. While 5 participants struggled to articulate the story's core ecological message, offering vague answers like "I don't know" or "not be a thief," others successfully grasped the key themes of not abandoning pets in natural areas and the importance of not littering. When asked about appropriate actions for abandoned pets, responses included "look for the owner," "give to the establishment," "take it to a shelter so it doesn't harm others," "call someone responsible", or "adopt the cat." For the Egg Thief Story, participants generally understood the correct action was to "clean it myself," with only 2 participants noting the crucial addition that this should be done "responsibly and only if it's safe, otherwise, call a responsible adult."

Regarding text comprehension and length, most participants found the text "easy to understand." However, 7 participants, particularly the two participants of Session 2 (9-year-olds), found the dialogues "too long" and admitted to "skipping" sections, especially between the first and second animal encounters. They frequently wished for "less dialogue," "more images," or for the text to be "shorter" or "summarized." Session 2 specifically noted having "a little trouble reading" and tending to "forget what they just read after a mini-game," indicating a challenge with information retention from dense text.

The preference for voice acting was strong among 8 participants, particularly those of Session 3. However, a small portion of participants did not want voice acting. One participant, S11LU (12-year-old girl) mentioned, "if you put human voices it's strange, but if it was more based on animal voices I think they would be fine." Another, participant S12SL (12-year-old girl), simply stated "No" to voice acting, while participant S21GA (9-year-old boy) was unsure, suggesting it "could take too long" but "maybe it would be good."

In terms of learning from the story, some participants claimed to have learned "about different animal species," "the care we must have with animals," or "to observe nature in a different way." The younger participants of Session 2 struggled to articulate specific new knowledge beyond the existence of certain species. A notable instance of information absorption occurred when one of the participants from Session 3, during a later lab tour, recognized a real-life "Freira da Madeira" (Zino's Petrel) by its character name "Dalila," demonstrating strong character association and retention of scientific information through the game's narrative. The varied comprehension levels between Session 2 (9 year-olds) and Session 1 and 3 (12-13 year-olds) suggested that the game's

content, particularly its textual complexity and morbid themes, might be better suited for the older end of the intended age range or require more tailored design for younger players.

4.4.3 AR and Map Mechanics:

The AR and map sections were mostly praised, however, some technical issues did issue negative feedback. Although participants enjoy navigation, the map's functionality, and lack thereof, received mixed, but predominantly negative, feedback. While 3 participants found it "easy and interesting" or reported "no problems," many across all age groups found it "difficult," "confusing," "not well organized," or "got a bit lost." A common request was for the "red circle", used as a static reference point of their location on the map to "move with them" , which was essentially them asking for real-time GPS tracking to be added. Those of Session 2 (9 year-olds) particularly struggled, stating they "didn't understand the map." Despite this difficulty and the game being designed for individual play, children, consistently in groups 3-4 people, often helped each other locate markers and overcome challenges. Many participants said that the exploration to find the AR markers was still fun, even with the "confusing map". In stark contrast, the AR experience was overwhelmingly positive. Participants described it as "cool", "fun", "intuitive," and "different", noting it was something they had "never done before." They especially enjoyed interacting with the real world and seeing the digital 3D overlays. These AR sections were frequently cited as the most enjoyable part of the game. Participant S32SI (13-year-old boy) provided detailed feedback: "I liked going to look for images in Augmented Reality (AR) and didn't find it difficult... I found it interesting to be in the real world and see these digital images, and it looked really good in the game.". The cloud finder mini-game was particularly popular. Participant S31BO (13-year-old boy) said: "I liked the cloud game," and participant S11LU (12-year-old girl) elaborated: "I liked the fog mini-game, it was cool to see the clouds in the real world."

AR functionality generally worked well, though some issues were reported, such as the AR camera briefly turning off on certain phones or difficulty scanning a specific image. Participant S21GA (9-year-old boy) initially "didn't understand that it was necessary to put the mini-games on the ground" to activate them. Some of the more hidden AR tracker images did require some guidance from the on location investigators. Some images were difficult to locate, with participant s11LU (12-year-old girl) noting, "I had difficulty finding one of the images because it was behind a tree."

7 participants felt the AR and map elements "complement the story well," viewing them as integral to the investigative narrative and enhancing curiosity. There was a strong preference for playing with the AR moments and a desire for "more mini-games" and "more AR scenes." Participant S32SI (13-year-old boy) provided detailed feedback: "I liked going to look for images in Augmented Reality (AR) and didn't find it difficult... I found it interesting to be in the real world and see these digital images, and it looked really good in the game."

Overall, AR was seen as beneficial for engaging with the natural world and encouraging exploration.

Regarding distraction from nature, responses were mostly positive. with 11 participants saying the AR segments did not distract them at all, with some even saying that they felt the AR helped them "focus on nature", however, other participants, like participant S15MI (12 year old girl), said that it did distract her a little bit, because she was looking at the phone.

Three participants, such as S36HU (13-year-old boy), said that the "The (AR) graphics don't mix well,". Participant S12SL (12-year-old girl) also stated "The graphics didn't mix well" but then followed it with "It (AR segments) helps me focus more on nature." These observations suggest that despite occasional visual blending imperfections, the overall act of using AR in nature was seen as beneficial for engaging with the natural world, actively encouraging exploration.

In terms of learning from AR, 11 participants felt they learned something, such as "about the fog in the ecological park," "animal habitat," or simply being "more focused on the game." However, the primary focus seemed to have been often on the AR experience itself rather than the didactic information it presented.

4.4.4 Closing thoughts, suggestions, and interest:

Responses regarding previous park visits were mixed, with some participants having visited before, some as young children, while others, particularly the younger participants, had not. 9 participants stated they had no prior knowledge about the specific ecological problems highlighted in the game.

Suggestions for changes to the application were varied but showed clear trends; a consistent request was for a moving GPS point, described as a "map ball follow us." Frequent suggestions, especially in Sessions 1 and 2, also included "less dialogue," "more images," and "shorter text" for improved readability and engagement. Participants expressed a desire for "more games," "more

AR scenes," and "more images to find," indicating their high enjoyment of interactive elements. Suggestions included adding "more sounds," "music," and for "characters to talk." One final specific request was to "add a team mode," reflecting the natural group play observed.

11 participants expressed a strong willingness to return to the park with the application and would recommend it to friends or family, often specifically mentioning cousins or friends. Some recommended it with the caveat of "less text." Finally, all participants expressed interest in using this type of application to learn about "other similar topics," "other school topics," or "more topics," finding it "more interactive" and helpful for understanding concepts better.

5 Discussion

The results of this study provide valuable insights into how Augmented Reality (AR) and location-based experiences can influence user engagement, educational outcomes, and overall experience, particularly within the 9-13 year old age range. The AR mini-games were, by far, the most popular aspect of the game across all participant sessions. Participants were much more engaged with these interactive AR experiences than with the narrative or educational content. Their primary motivation for continuing to play was often the desire to experience all the different AR mini-games, rather than exploring the story's plot or learning about the environment. This suggests that, while the AR elements were exciting and engaging, they did not consistently succeed in drawing children's attention toward the storyline or the integrated educational material. This presents an interesting challenge: while the AR features were clearly a hit, they may have overshadowed the educational and narrative aspects of the game. To address this, future iterations could explore ways to integrate educational content more directly into AR experiences, making it an essential part of the gameplay. For example, incorporating AR-based challenges that require players to apply knowledge about the park's species or ecosystem could encourage deeper engagement with the content.

Despite this, the AR components still hold significant potential. They can serve as a powerful tool for encouraging children to visit the park in real life. By making the park more interactive and providing a sense of adventure, the game could strengthen children's connection to the location and foster an interest in exploring it beyond the digital experience. However, to assess the true long-term impact of the game on children's engagement with the park, a longitudinal study would be necessary to track whether it leads to more frequent visits and a deeper connection to the natural environment.

The study revealed that the game needs to refine how it integrates educational elements into gameplay, as engagement with the scientific content was limited. Participants' understanding of the ecological issues presented, such as pet abandonment and littering, was often minimal. 12 of the participants weren't able to consistently and accurately explain the full message of the story or the ecologically correct action to take if they found an abandoned cat. Most said they would try to "adopt the cat," which, while demonstrating compassion, does not align with the game's core educational message about the harm abandoned pets cause to ecosystems. This highlights the need for clearer communication and more effective methods of reinforcing the moral and educational

messages through gameplay. Several challenges were identified, including difficulties with navigation caused by the non-interactive map and issues with text comprehension among younger players. Safety concerns were also raised by some parents, particularly regarding the park's lower area's proximity to roads, emphasizing the need for careful consideration of area limits in Location-Based games to avoid situations where children might encounter traffic. These challenges underscore the importance of designing intuitive gameplay mechanics and refining educational content delivery to better engage the target audience. During the study, new design opportunities emerged. Despite efforts to mitigate group formation, all users chose to stay together throughout the experience. While this limited individual divergence, it highlighted a potential opportunity for future versions of "Eco Detectives" to foster social interaction, which could enhance user engagement, particularly as previous studies indicate that users often rely on peers when encountering difficulties with AR apps [5]. This peer influence should be considered not only in future AR application development but also in the design of study protocols.

Participants across all sessions praised the character designs, describing them as appealing and charming. There were also suggestions to include greater visual variety and the addition of animal-like voices to enhance immersion and character identity. While most participants desired voice acting, a small portion of participants did not want voice acting, with one 12-year-old participant specifically suggesting that human voices might be "strange" and that "animal voices" might be better.

Navigation challenges were exacerbated by the use of a static map. Several participants, particularly the 9-year-olds, struggled to locate scannable image markers and expressed frustration at the lack of real-time location features that would have allowed for more intuitive navigation. This static interface, combined with vague directions, often led to confusion and slowed down the pace of gameplay. Introducing a GPS-enabled dynamic map could be a crucial addition to improve usability and reduce confusion.

A significant finding was the wide developmental gap within the 9-to-13 year old target age range. The older participants (12-13 year olds) generally experienced fewer issues with the game's features compared to their younger counterparts (9-year-olds). Specifically, 12-13 year olds exhibited greater proficiency in navigating the static map, more consistent engagement with the narrative (though still prone to skipping longer texts), and a quicker grasp of the AR mechanics.

In contrast, the 9-year-olds notably struggled with reading the text-heavy narrative, had significant difficulty orienting themselves with the map, and sometimes required more guidance on how to interact with the AR mini-games, highlighting how rapidly children develop cognitive abilities within these formative years. This suggests that the "tween" age range is too broad for a single, undifferentiated game design, as the abilities and engagement patterns of a 9-year-old can differ dramatically from those of a 12 or 13-year-old.

5.1 Analysis of Research Questions

5.1.1 Research Question 1: How does the combination of AR, player motion, non-linear interactive narratives, and location-based experiences affect user experience and behavior, particularly the balance between engagement with interactive elements and absorption of narrative content?

The addition of AR and physical movement played a central role in maintaining the children's interest throughout the study. The physical exploration of Funchal's Ecological Park added an immersive and engaging dimension to the experience, significantly influencing participant behavior. Children enjoyed moving around the park, seeking out hidden AR elements, and participating in mini-games. These aspects of the game actively encouraged children to interact with the environment, promoting curiosity and physical activity. However, the strong focus on exploration and AR mechanics meant that children occasionally disregarded the narrative and educational aspects. Across all sessions, children were more captivated by the process of searching for AR mini-games and characters than by understanding the deeper ecological themes embedded in the story. This suggests that while physical exploration and AR elements enhanced the user experience by creating a dynamic and fun activity, they also created a potential diversion from the educational and narrative goals.

In terms of behavior, Session 3 and Session 2 were more adept at engaging with the AR features, demonstrating higher levels of enthusiasm for the interactivity. However, their engagement with the branching narrative was often limited, suggesting that while the AR features were highly motivating, they could overshadow the importance of the story. Session 1, on the other hand, struggled more with basic game mechanics, particularly in terms of navigation and using the map. Their attention was more on exploration than on following the game's storyline or completing narrative tasks. This pattern of behavior suggests that while AR and player motion can significantly

enhance engagement, the game's design must ensure a clear balance between interactive elements and the narrative to avoid overshadowing educational content.

Another possible contributing factor to disengagement with the narrative may have been the abrupt contrast between interactive AR segments and the visual novel format used for storytelling. This stylistic shift could have created a disconnect, making it harder for players to stay immersed in the storyline. Additionally, several participants exhibited signs of reading fatigue, particularly during longer narrative segments. This fatigue likely contributed to difficulties in retaining educational content and connecting it with in-game actions. A more seamless and dynamic delivery method could help sustain engagement and comprehension.

5.1.2 Research Question 2: How does the combination of AR, non-linear interactive narratives, and a location-based experiences affect children's comprehension and retention of scientific knowledge and moral lessons related to ecological issues?

While the game aimed to present ecological knowledge and moral lessons, the study revealed that the integration of AR and the branching narrative was not sufficiently effective in consistently conveying these messages to all participants. Despite interacting with AR elements referencing biodiversity, wildlife, and environmental issues, children did not always fully grasp the ecological implications of the content.

Session 3 and Session 2 showed some curiosity about the branching narrative and expressed interest in replaying to explore different story outcomes. However, their engagement remained primarily focused on the AR interactions rather than the educational content about pet abandonment and littering. They found the AR elements to be much more engaging than the narrative itself. This may have been due, in part, to the separation between the narrative and AR elements. The narrative was presented in a traditional visual novel-like format, which involved reading long text passages. While the content might have been informative, the reading-based nature of the narrative might not have captured children's attention in the same way the interactive AR features did. The visual novel format, which requires sustained focus on reading, could have been a barrier to engagement, especially for younger players who might have found it challenging to remain attentive for extended periods.

Session 1, in particular, had difficulty processing the narrative, as the text-heavy structure overwhelmed them. They often forgot the content after completing AR tasks, further suggesting that the separation of the narrative from the AR elements made it harder for children to connect the two. The game's design might not have effectively captured their attention in a way that made the ecological messages resonate. The extended nature of the narrative was seen as too lengthy, even though certain sections were entertaining. This feedback points to a potential disconnect between the engaging AR features and the more passive experience of reading through a lengthy story, which might not have held children's interest long enough to fully absorb the educational content.

The children's focus on exploration and AR rather than narrative suggests that the game would benefit from a more integrated approach, where the story and AR features are closely tied together. This could involve making the narrative more dynamic and interactive, perhaps by incorporating in-game choices, character interactions, or visual storytelling directly influenced by AR elements. The visual novel-like format, which relies heavily on reading and less on direct interaction, might have been less appealing for younger players due to a lack of reading experience or a preference for more active pieces of media, such as cartoons and more traditional video game experiences.

5.1.3 Research Question 3: What are the pedagogical, technical, and design challenges and benefits of creating a location-based experience using AR and a non-linear interactive narrative for children aged 9-13?

The study highlighted several benefits and challenges related to creating a location-based game with AR and a branching narrative.

Benefits: Immersive Learning Experience: The location-based nature of the game in the Ecological Park allowed participants to physically engage with the natural environment, creating an immersive learning experience. The AR features brought elements of the park's biodiversity to life, offering a unique opportunity for children to explore the park and learn about its ecosystems in a hands-on manner. **Physical Activity and Exploration:** The physical exploration of the park was a significant benefit, providing children with an active experience that combined education with outdoor play. The interaction with the environment through AR elements, such as virtual animals and hidden objects, kept children engaged and motivated to explore further.

Incentive for Further Playthroughs: Although many players did not choose either story branches equally, particularly most leaving the one related to the Egg Thieves behind, upon learning about other characters, they expressed interest in what they looked like, what animal they were based on, and whether there were other mini-games they had not yet experienced. This indicates a strong incentive for replayability based on discovering new content.

Challenges: Narrative Integration: One of the main challenges was effectively integrating the narrative with the AR elements. Children were more focused on the physical exploration and interactive tasks than the story itself. The narrative may not have been sufficiently compelling or engaging for the target age group, especially given that some children struggled to process the text-heavy content. The length of the text was a particular concern; while some children found parts of the narrative entertaining, others felt it was too long and would have preferred a more concise version. The need for a more engaging and streamlined narrative became evident, as children found long introductions less appealing and struggled to stay engaged with the educational material. While the AR elements enhanced interaction with the environment and engaged participants, they were not always intuitively connected to the branching narrative, leading to moments of disinterest from participants.

Usability: Another significant challenge was ensuring that the game mechanics, particularly the map and navigation, were user-friendly for all players, especially younger participants. Session 1 faced considerable difficulties in navigating the park and using the static map to locate AR elements, which significantly hindered their overall experience. A specific usability issue was the reliance on a static map, which did not offer real-time guidance. Younger participants often found it difficult to orient themselves or determine their exact location in the park. This static interface, combined with vague directions, sometimes led to confusion and slowed down the pace of gameplay.

Age Range Discrepancy: The study clearly demonstrated that the "tween" age range of 9-13 years old is still too broad for a single, undifferentiated game design. There was a notable developmental gap, with 9-year-olds facing considerably more challenges with reading comprehension, map navigation, and maintaining narrative engagement compared to 12-13 year olds. This highlights that children within these very formative years develop rapidly, necessitating more targeted content and mechanic design.

Finally, we would like to add a reflection made at the end of the evaluation process. It became evident that the sequential development approach, where we began with a previous project focused on a visual novel framework and subsequently integrated AR mechanics in the present iteration, fundamentally shaped the player experience in ways that were not initially anticipated. While AR components proved highly engaging and successfully encouraged players to interact with their physical environment rather than remaining focused on their screens, this enthusiasm came at the cost of narrative coherence, creating a disconnect between the game's interactive and narrative elements. Reflecting on this outcome, the decision to conceptualize AR as an enhancement to an already existent story-driven structure, rather than as foundational element from the outset, likely contributed to this imbalance. Had the AR mechanics been integrated into the core of the design from the start, with the narrative and educational content woven into the AR elements, the result may have been a more cohesive experience where story, learning and play reinforced rather than competed with one another.

5.2 Limitations

This study encountered some limitations that influenced its scope and the execution of the research, primarily stemming from logistical hurdles and the inherent technical constraints of the main researcher.

A significant limitation stemmed from the primary researcher's technical skills as a programmer. The ability to implement more complex mechanics and enhancements that could have streamlined gameplay, improved educational content integration, or added more robust interactive elements was constrained by technical capacity, leading to necessary trade-offs in the game's design and functionality.

Beyond technical aspects, recruiting participants and conducting the study in the chosen location presented considerable logistical challenges. The Funchal Ecological Park, while an ideal setting for an environmental game due to its natural context, is a remote location situated far from more densely populated city areas of Madeira. This geographical isolation made recruiting participants difficult, as it demanded significant travel and time commitment from families and guardians to bring children to the study site or find public transportation to bring them. The strenuous nature of accessing the park directly resulted in a lower participant count than initially desired for a comprehensive and broadly generalizable study. Consequently, the findings, while valuable, are

drawn from a smaller sample size, which may affect their generalizability to a wider population of children. Overcoming these accessibility barriers would be crucial for any future research aiming for a larger and more diverse participant pool.

Regarding the scope of the content, while the transition to a concentric non-linear narrative was designed to enhance replayability, a current limitation is the volume of available content. In its present state, the prototype features two narrative paths, realistically, this allows for only two unique playthroughs before the user exhausts most of the relevant content.

Furthermore, because the study was limited to a single visit to the ecological park per participant session, long-term engagement could not be measured. Instead, interest in multiple future playthroughs was gauged through the participants' immediate interest in returning to the game to experience the second story. To truly evaluate the long-term effectiveness of the project, additional visits would be required, alongside a broader variety of content to further differentiate every session after the second.

5.3 Future Work

Based on the insights gained from this study, future iterations of the game should focus on the following improvements:

Navigation emerged as a primary usability barrier, particularly with the static map. The system will be upgraded with a real-time GPS map (See Fig. 24) system for continuous user tracking, resolving the need for abstract spatial reasoning among early adolescents and improving immersion.

However, while participants requested precise GPS functionality, this raises an interesting design tension between ease of navigation and preserving exploratory and immersive gameplay, by allowing them to simply take a straight line towards the correct location. Future research could investigate whether GPS-guided navigation diminishes the sense of discovery in location-based games, especially in smaller locations such as our experiment grounds (around 7800 m^2). A GPS infrastructure would facilitate a transition to a markerless AR system, anchoring virtual objects directly to real-world coordinates. This not only enhances the game's stability but fundamentally integrates the digital content and the physical park environment, addressing the observed tension between screen focus and nature observation.

A hint system could be added with the intent to help those struggling with the map. By tapping on the location they wish to find, they will get an image of the surrounding location (See Fig. 24-B).

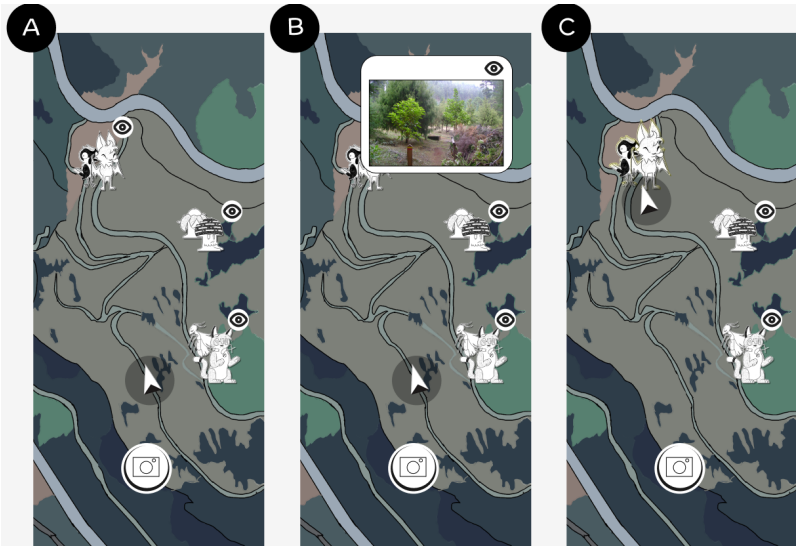

Figure. 24: Image of the new map system, showcasing the UI, hint system, and GPS.

Although AR proved to greatly engage users, this captivation likely overshadowed and potentially clashed with the storytelling and educational content delivered in the Visual Novel moments. To address the observed lack of cohesion between story delivery and AR gameplay, and to better engage users with the educational content, the static, text-heavy Visual Novel format could be fully integrated into the AR segments (See Fig. 25). This redesign would ensure the delivery of educational content and narrative clues are contextualized within the interactive AR environment, avoiding the passive text reading that contributed to poor knowledge retention.

Educational content should be delivered in shorter, more digestible segments, possibly through making animal character interactions more interactive, such as add an interrogation mechanic, rather than using mostly uninterrupted text passages. In regards to the initial cognitive barrier of the lengthy introduction, this could be resolved by replacing it with optional pre-visit media, such as a digital comic or short prologue animation. This strategy could efficiently deliver the necessary narrative context, allowing users to transition into active AR gameplay much quicker. To further mitigate issues with reading fatigue, the game could also incorporate voice acting and more animated sprites and backgrounds. These approaches may reduce the cognitive load associated with long reading segments while increasing immersion.

The AR mini-games should also be redesigned to offer more complex interactions that are more tightly tied to the narrative. These games should challenge players and encourage them to think critically about the ecological issues they are encountering.

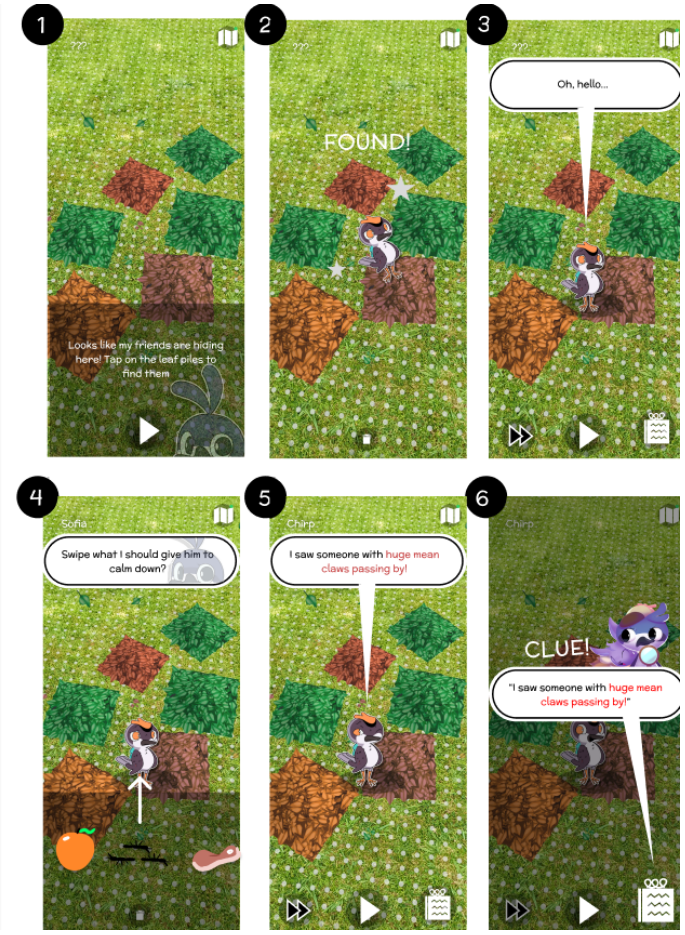

Figure. 25: Images of the narrative being implemented into the AR mini-games. Follow numbered order.

A significant observation across the sessions was the substantial developmental differences observed across different ages. Future design efforts should consider whether to create distinct versions or just a single game tailored for specific sub-segments within the tween, 9-13, age range. This consolidation would allow for the integration of more age-appropriate ways to deliver scientific concepts and abstract gameplay mechanics, directly addressing the difficulty younger participants experienced with cognitive load and sustained attention, or further challenging older participants.

In regards to emerging group tendencies, our original intent was for this project to be a solo experience. However, as mentioned before, throughout the experiment, participants in each session

eventually ended up grouping together Whilst this does go against our original idea, this does present an interesting path for future iterations and projects to follow up on.

We propose two distinct approaches: a comprehensive Co-op redesign and a competitive Versus side mode.

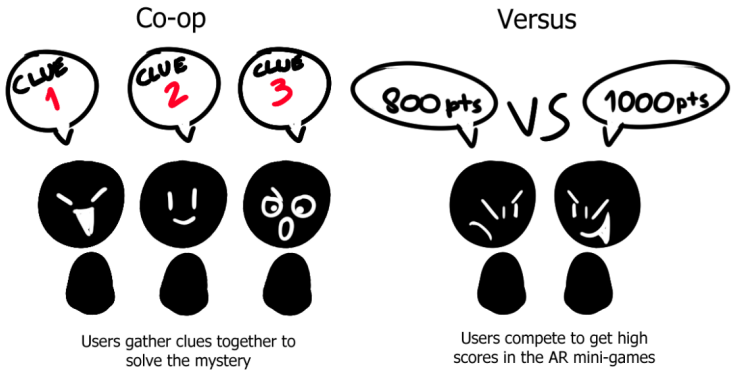

Figure. 26: Multiplayer possibilities: Co-op gathering or Versus competition.

5.3.0.1 The Co-op Version (Core Redesign):

This version represents a complete architectural and narrative overhaul, fundamentally embedding group investigation into the mystery's foundation. It mandates collaboration to solve the crime.

Upon starting, players can initiate a private room system to synchronize their game state, ensuring all participants share location guidance and progress. All collected clues are instantly shared and synchronized across all linked devices, requiring the group to meet at the final stage to debate their combined findings and eliminate suspects.

5.3.0.2 The Versus Version (Side Mode):

A Versus mode serves as a competitive side mode or add-on, allowing children who play the game by themselves to later connect with friends. It maintains the original solo experience structure with an added competitive layer.

Players follow the standard non-linear solo path but compete against linked players to achieve the highest score or fastest completion time in the AR mini-games. A more pronounced score or time-based competitive element will be introduced exclusively for the AR mini-games. Scores will be tracked and displayed in a real-time leaderboard for the synchronized group, adding an element of direct competition without affecting the individual player's narrative outcome. par Crucially, both

the Co-op and Versus models require extensive, targeted testing. While multiplayer is intended to boost engagement, there is a risk that group dynamics, whether cooperative or competitive, could lead to social loafing, distraction, or excessive focus on winning. These factors could inadvertently detract from the core educational content and nature observation goals of the application. Future prototyping must prioritize measuring knowledge acquisition and attention maintenance alongside social engagement metrics for both proposed designs.

6 Conclusion

This paper showcased Eco Detectives, showing its inherent strengths in engaging players through nonlinear Interactive storytelling, AR interactions and physical exploration within a real-world environment. The results revealed that while children within the tween age group (9-13 years old) were undeniably captivated by the AR features and the active exploration of Funchal's Ecological Park, these compelling aspects often overshadowed the game's narrative and deeper educational content. There were considerable challenges in consistently integrating the educational material into the gameplay, particularly for the younger demographic. While participants showed interest in the park's species, and some grasped overarching environmental themes, their understanding of the deeper ecological issues, such as the specific harms of pet abandonment and the precise actions required, remained limited. Participants notably struggled to connect the narrative's lessons with real-world, ecologically sound actions. This indicates a clear need for better integration of educational material directly within the gameplay, ensuring that environmental lessons are not sidelined by the excitement of the interactive elements.

The game's nonlinear narrative structure holds significant potential, as it encourages replayability and deeper engagement, offering a promising avenue for refining how the narrative evolves to integrate both educational content and storyline more seamlessly.

Furthermore, the game's design faced several usability challenges. The reliance on a static map without real-time GPS tracking proved to be a significant hurdle for navigation, and the text-heavy narrative also presented a barrier, particularly for the younger players, who frequently skipped longer dialogue sections, impacting their comprehension and retention of key story and educational details. Moreover, the observed natural tendency for participants to form collaborative groups, despite the game's individual design, highlighted a missed opportunity for fostering social interaction within the gameplay.

This study particularly underscored that the "tween" age range of 9-13 years old encompasses a wide developmental gap, with older participants (12-13 year olds) generally experiencing fewer issues with the game's features compared to their younger counterparts (9-year-olds), suggesting that a more focused target audience or differentiated content might be beneficial for future iterations. These elements collectively indicate a need for refinement to ensure the experience is not only engaging and educational but also consistently accessible and enjoyable across the entire 9-13

year old target age group Despite these challenges, the overall feedback from participants was overwhelmingly positive, with all expressing strong interest in revisiting the park with the application and recommending it to others. This demonstrates the significant promise of location-based AR experiences as powerful tools for learning and engagement in natural environments.

Future work will focus on refining game mechanics, improving the AR mini-games, and streamlining the narrative for a more seamless experience. With these improvements, Eco Detectives can become a powerful tool for fostering lasting environmental awareness among children, encouraging both interactive learning and a deeper connection to nature.

References

[1] Abbott, H.P.: Defining narrative, p. 13–27. Cambridge Introductions to Literature, Cambridge University Press (2008)

[2] Alnagrat, A., Ismail, R., Syed Idrus, S.Z.: A review of extended reality (xr) technologies in the future of human education: Current trend and future opportunity. Journal of Human Reproductive Sciences **1** (08 2022). https://doi.org/10.11113/humentech.v1n2.27

[3] Basaraba, N.: A communication model for non-fiction interactive digital narratives: A study of cultural heritage websites. Frontiers of Narrative Studies **4**(s1), s48–s75 (2018). https://doi.org/doi:10.1515/fns-2018-0032, https://doi.org/10.1515/fns-2018-0032

[4] Benford, S.: Future location-based experiences. JISC: Technology & Standards Watch (2005)

[5] Bodén, M., Dekker, A., Viller, S., Matthews, B.: Augmenting play and learning in the primary classroom. In: Proceedings of the 12th International Conference on Interaction Design and Children. p. 228–236. IDC '13, Association for Computing Machinery, New York, NY, USA (2013). https://doi.org/10.1145/2485760.2485767, https://doi.org/10.1145/2485760.2485767

[6] Bostan, B., Marsh, T.: Etkileşimli hikayeciliğin temelleri. AJIT-e: Academic Journal of Information Technology **3**(8), 19–42 (2012). https://doi.org/10.5824/1309-1581.2012.3.002.x

[7] Brondízio, E., Settele, J., Diaz, S., Ngo, H.T., Experts, G., Mohamed, A.: Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Zenodo (06 2021). https://doi.org/10.5281/zenodo.383188

[8] Browning, M.H.E.M., Mimnaugh, K.J., Van Riper, C.J., Laurent, H.K., LaValle, S.M.: Can Simulated Nature Support Mental Health? Comparing Short, Single-Doses of 360-Degree Nature Videos in Virtual Reality With the Outdoors. Frontiers in Psychology **10**, 2667 (Jan 2020). https://doi.org/10.3389/fpsyg.2019.02667, https://www.frontiersin.org/article/10.3389/fpsyg.2019.02667/full

[9] Burls, A.: People and green spaces: Promoting public health and mental well-being through ecotherapy. Journal of Public Mental Health **6** (09 2007). https://doi.org/10.1108/17465729200700018

[10] Carline, J.: Nature treks vr (2017), https://store.steampowered.com/app/587580/Nature_Treks_VR/, (accessed: 12.02.2024)

[11] Cederqvist, A.M., Thorén Williams, A.: An exploratory case study on student teachers' experiences of using the ar app seek by inaturalist when learning about plants. In: Zaphiris, P., Ioannou, A. (eds.) Learning and Collaboration Technologies. pp. 33–52. Springer Nature Switzerland, Cham (2023)

[12] Chang, J., Kim, S.H., Shim, J., Ma, D.: Who is responsible for climate change? attribution of responsibility, news media, and south koreans' perceived risk of climate change. Mass Communication and Society **19** (06 2016). https://doi.org/10.1080/15205436.2016.1180395

[13] Chawla, L., Derr, V.: 527 the development of conservation behaviors in childhood and youth. In: The Oxford Handbook of Environmental and Conservation Psychology. Oxford University Press (09 2012). https://doi.org/10.1093/oxfordhb/9780199733026.013.0028, https://doi.org/10.1093/oxfordhb/9780199733026.013.0028

[14] Cheng, A.Y., Ritchie, J., Agrawal, N., Childs, E., DeVeaux, C., Jee, Y., Leon, T., Maples, B., Cuadra, A., Landay, J.A.: Designing immersive, narrative-based interfaces to guide outdoor learning. In: Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems. CHI '23, Association for Computing Machinery, New York, NY, USA (2023). https://doi.org/10.1145/3544548.3581365

[15] Cypher, M.: Biophilia. In: ACM SIGGRAPH 2006 Sketches. p. 24–es. SIGGRAPH '06, Association for Computing Machinery, New York, NY, USA (2006). https://doi.org/10.1145/1179849.1179879, https://doi.org/10.1145/1179849.1179879

[16] Dadvand, P., Gascon, M., Markevych, I.: Green Spaces and Child Health and Development, pp. 121–130. Springer International Publishing, Cham (2019). https://doi.org/10.1007/978-3-030-02318-8_6, https://doi.org/10.1007/978-3-030-02318-8_6

[17] Díaz, S., Settele, J., Brondízio, E.S., Ngo, H.T., Agard, J., Arneth, A., Balvanera, P., Brauman, K.A., Butchart, S.H.M., Chan, K.M.A., Garibaldi, L.A., Ichii, K., Liu, J., Subramanian, S.M., Midgley, G.F., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., Polasky, S., Purvis, A., Razzaque, J., Reyers, B., Chowdhury, R.R., Shin, Y.J., Visseren-Hamakers, I., Willis, K.J., Zayas, C.N.: Pervasive human-driven decline of life on earth points to the need for transformative change. Science **366**(6471), eaax3100 (2019). https://doi.org/10.1126/science.aax3100, https://www.science.org/doi/abs/10.1126/science.aax3100

[18] Ellis, E.C.: Anthropocene: A Very Short Introduction. Oxford University Press (03 2018). https://doi.org/10.1093/actrade/9780198792987.001.0001, https://doi.org/10.1093/actrade/9780198792987.001.0001

[19] Fall, I.: Night in the woods (2017), https://www.nightinthewoods.com/, (accessed: 03.06.2025) Video Game

[20] Fernandes, F.: Eco Detectives - Research Project. YouTube (2025), https://www.youtube.com/watch?v=mW3CMWDXi_U, (accessed: 13.09.2025)

[21] Fernandes, L.F., Bala, P., Olim, S.C., Campos, P.F., Dionisio, M.: Combining Interactive Narratives and Augmented Reality to Promote Engagement between Children and Nature, p. 858–862. Association for Computing Machinery, New York, NY, USA (2025). https://doi.org/doi/10.1145/3713043.3731496, https://doi.org/10.1145/3713043.3731496

[22] Freitas, A., Fernandes, F., Dionísio, M., Olim, S.: Mystery in the ecological park: An interactive narrative to promote interaction with biodiversity. In: Entertainment Computing – ICEC 2023: 22nd IFIP TC 14 International Conference, ICEC 2023, Bologna, Italy, November 15–17, 2023, Proceedings. p. 360–364. Springer-Verlag, Berlin, Heidelberg (2023). https://doi.org/10.1007/978-981-99-8248-6_32, https://doi.org/10.1007/978-981-99-8248-6_32

[23] do Funchal, M.: 2.ª edição da competição dr. why "uma só terra! – plástico + ambiente" (2024), https://pem.funchal.pt/2-a-edicao-da-competicao-dr-why-uma-so-terra-plastico-ambiente/, (accessed: 07.04.2025)

[24] Geldmann, J., Manica, A., Burgess, N.D., Coad, L., Balmford, A.: A global-level assessment of the effectiveness of protected areas at resisting anthropogenic

pressures. Proceedings of the National Academy of Sciences **116**(46), 23209–23215 (2019). https://doi.org/10.1073/pnas.1908221116, https://www.pnas.org/doi/abs/10.1073/pnas.1908221116

[25] Geyer, R., Jambeck, J., Law, K.: Production, use, and fate of all plastics ever made. Science Advances **3**, e1700782 (07 2017). https://doi.org/10.1126/sciadv.1700782

[26] Google: Google cardboard (2025), https://arvr.google.com/cardboard/, (accessed: 03.12.2023)

[27] Grassini, S.: A systematic review and meta-analysis of nature walk as an intervention for anxiety and depression. Journal of Clinical Medicine **11**(6) (2022). https://doi.org/10.3390/jcm11061731, https://www.mdpi.com/2077-0383/11/6/1731

[28] Hsu, Y.C.: Exploring the learning motivation and effectiveness of applying virtual reality to high school mathematics. Universal Journal of Educational Research **8**, 438–444 (02 2020). https://doi.org/10.13189/ujer.2020.080214

[29] International, B.: State of the world's birds: taking the pulse of the planet (2018), https://www.birdlife.org/wp-content/uploads/2021/02/SOWB2018_en.pdf, (accessed: 05.12.2023)

[30] Jenkins, H.: Game design as narrative architecture. Computer **44** (01 2002)

[31] Kamarainen, A.M., Metcalf, S., Grotzer, T., Browne, A., Mazzuca, D., Tutwiler, M.S., Dede, C.: Ecomobile: Integrating augmented reality and probeware with environmental education field trips. Computers & Education **68**, 545–556 (2013). https://doi.org/https://doi.org/10.1016/j.compedu.2013.02.018, https://www.sciencedirect.com/science/article/pii/S0360131513000572

[32] Kawas, S., Kuhn, N.S., Tari, M., Hiniker, A., Davis, K.: "otter this world": can a mobile application promote children's connectedness to nature? In: Proceedings of the Interaction Design and Children Conference. p. 444–457. IDC '20, Association for Computing Machinery, New York, NY, USA (2020). https://doi.org/10.1145/3392063.3394434, https://doi.org/10.1145/3392063.3394434

[33] Kollmuss, A., Agyeman, J.: Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? Environmental Education Research **8**, 239–260

(08 2002). https://doi.org/10.1080/13504620220145401

[34] Kumar, P., Sahani, J., Rawat, N., Debele, S., Tiwari, A., Emygdio, A.P., Kooloth Valappil, A., Kukadia, V., Holmes, K., Pfautsch, S.: Using empirical science education in schools to improve climate change literacy. Renewable and Sustainable Energy Reviews **178** (05 2023). https://doi.org/10.1016/j.rser.2023.113232

[35] Kumar, V., Choudhary, S., Singh, R.: Environmental socio-scientific issues as contexts in developing scientific literacy in science education: A systematic literature review. Social Sciences & Humanities Open **9** (12 2023). https://doi.org/10.1016/j.ssaho.2023.100765

[36] Kumpulainen, K., Byman, J., Renlund, J., Wong, C.C.: Children's augmented storying in, with and for nature. Education Sciences **10**, 149 (05 2020). https://doi.org/10.3390/educsci10060149

[37] Kumpulainen, K., Byman, J., Renlund, J., Wong, C.C.: Children's augmented storying in, with and for nature. Education Sciences **10**(6) (2020). https://doi.org/10.3390/educsci10060149, https://www.mdpi.com/2227-7102/10/6/149

[38] Laato, S., Fernández Galeote, D., Altarriba Bertran, F., Papangelis, K., Hamari, J.: How location-based games incentivize moving about: A study in the context of nature-going. Proceedings of the ACM on Human-Computer Interaction **7** (10 2023). https://doi.org/10.1145/3611044

[39] Lazer, G.: Planet stories ar, https://play.google.com/store/apps/details?id=com.GiantLazer.PlanetStoriesAR&hl=pt&gl=US&pli=1, (accessed: 06.02.2024)

[40] Lazer, G.: Trash rage vr - first ecologically themed vr game (nd), https://giantlazer.com/trash-rage-vr-game/, (accessed: 07.04.2025)

[41] Le Noury, P., Polman, R., Maloney, M., Gorman, A.: A Narrative Review of the Current State of Extended Reality Technology and How it can be Utilised in Sport. Sports Medicine **52**(7), 1473–1489 (Jul 2022). https://doi.org/10.1007/s40279-022-01669-0, https://doi.org/10.1007/s40279-022-01669-0

[42] Li, W., Li, C., Kim, M., Huang, H., Yu, L.F.: Location-aware adaptation of augmented reality narratives. In: Proceedings of the 2023 CHI Conference on Human Factors in Comput-

ing Systems. CHI '23, Association for Computing Machinery, New York, NY, USA (2023). https://doi.org/10.1145/3544548.3580978, https://doi.org/10.1145/3544548.3580978

[43] Loss, S., Will, T., Marra, P.: The impact of free-ranging domestic cats on wildlife of the united states. Nature communications **4**, 1396 (01 2013). https://doi.org/10.1038/ncomms2380

[44] Lumber, R., Richardson, M., Sheffield, D.: Beyond knowing nature: Contact, emotion, compassion, meaning, and beauty are pathways to nature connection. PLOS ONE **12**(5), 1–24 (05 2017). https://doi.org/10.1371/journal.pone.0177186, https://doi.org/10.1371/journal.pone.0177186

[45] Makri, A., Vlachopoulos, D., Martina, R.A.: Digital escape rooms as innovative pedagogical tools in education: A systematic literature review. Sustainability **13**(8) (2021). https://doi.org/10.3390/su13084587, https://www.mdpi.com/2071-1050/13/8/4587

[46] Media, E.L.: Beyond blue (2020), https://store.steampowered.com/app/883360/Beyond_Blue/, (accessed: 06.02.2024)

[47] Menconi, M., Abbate, R., Stocchi, S., Grohmann, D.: Nature-related education and serious gaming to improve young citizens' awareness about ecosystem services provided by urban trees. Ecosystem Services **73** (03 2025). https://doi.org/10.1016/j.ecoser.2025.101715

[48] Microsoft: Microsoft hololens - tecnologia de realidade mista para empresas (nd), https://www.microsoft.com/pt-pt/hololens, (accessed: 03.12.2023)

[49] Milgram, P., Kishino, F.: A taxonomy of mixed reality visual displays. IEICE Trans. Information Systems **vol. E77-D, no. 12**, 1321–1329 (12 1994)

[50] Moir, J., Kwansa, T.: Interviewing children for the purposes of research in primary care. Primary Health Care Research and Development **1** (04 2000). https://doi.org/10.1191/146342300675316801

[51] for Conservation of Nature (IUCN), I.U.: Iucn red list of threatened species, https://www.iucnredlist.org/, (accessed: 03.12.2023)

[52] for Conservation of Nature (IUCN), I.U.: The iucn red list of threatened species. version 2020-1, https://nc.iucnredlist.org/redlist/resources/files/1630480997-

IUCN_RED_LIST_QUADRENNIAL_REPORT_2017-2020.pdf, (accessed: 03.12.2023)

[53] de Florestas e Conservação da Natureza, I.: Programa de educação ambiental (nd), https://ifcn.madeira.gov.pt/divulgacao/programa-de-educacao-ambiental.html, (accessed: 27.04.2025)

[54] Negrete, A.: Fact via Fiction: Stories that Communicate Science, pp. 95–102. The Pantaneto Press (01 2005). https://doi.org/10.13140/RG.2.1.5110.1207

[55] Niantic, Inc.: Pokémon go, https://pokemongolive.com/pt_br/, (accessed: 11.09.2023)

[56] Nintendo: The legend of zelda: Breath of the wild (2017), https://www.nintendo.com/pt-pt/Jogos/Jogos-para-a-Nintendo-Switch/The-Legend-of-Zelda-Breath-of-the-Wild-1173609.html, (accessed: 06.03.2024)

[57] Nintendo: Nintendo labo™ toy-con 04 vr kit (2025), https://www.nintendo.com/my/switch/adfx/index.html, (accessed: 03.12.2023)

[58] Nisi, V., Oakley, I., Haahr, M.: Location-aware multimedia stories: turning spaces into places. Universidade Cátolica Portuguesa (2008)

[59] O'Hara, K., Kindberg, T., Glancy, M., Baptista, L., Sukumaran, B., Kahana, G., Rowbotham, J.: Collecting and sharing location-based content on mobile phones in a zoo visitor experience. Comput Supported Cooperative Work **16**, 11–44 (04 2007). https://doi.org/10.1007/s10606-007-9039-2

[60] Oppermann, L.: Facilitating the Development of Location-Based Experiences. Ph.D. thesis, University of Nottingham (04 2009), https://eprints.nottingham.ac.uk/id/eprint/14215

[61] Paavilainen, J., Korhonen, H., Alha, K., Stenros, J., Koskinen, E., Mayra, F.: The pokémon go experience: A location-based augmented reality mobile game goes mainstream. In: Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. CHI '17, Association for Computing Machinery, New York, NY, USA (2017). https://doi.org/10.1145/3025453.3025871

[62] Paxton, R., McKeown, M.: The climate and ecological crisis – responsible but not to blame. The Psychologist (June 2024), https://www.bps.org.uk/psychologist/climate-and-ecological-crisis-responsible-not-blame, british Psychological Society

[63] Prandi, C., Nisi, V., Loureiro, P., Nunes, N.: Storytelling and remote-sensing playful interventions to foster biodiversity awareness. International Journal of Arts and Technology **12**, 39 (01 2020). https://doi.org/10.1504/IJART.2020.107680

[64] Radu, I., Macintyre, B.: Using children's developmental psychology to guide augmented-reality design and usability. In: ISMAR 2012 - 11th IEEE International Symposium on Mixed and Augmented Reality 2012, Science and Technology Papers (11 2012). https://doi.org/10.1109/ISMAR.2012.6402561

[65] Resort, U.O.: Super nintendo world (2025), https://www.universalorlando.com/web/en/us/epic-universe/worlds/super-nintendo-world, (accessed: 03.06.2025)

[66] Rode, v., Torkar, G.: The inaturalist application in biology education: A systematic review. International Journal of Educational Methodology **9**, 725–744 (11 2023). https://doi.org/10.12973/ijem.9.4.725

[67] Ruan, S., He, J., Ying, R., Burkle, J., Hakim, D., Wang, A., Yin, Y., Zhou, L., Xu, Q., AbuHashem, A., Dietz, G., Murnane, E.L., Brunskill, E., Landay, J.A.: Supporting children's math learning with feedback-augmented narrative technology. In: Proceedings of the Interaction Design and Children Conference. IDC '20, Association for Computing Machinery, New York, NY, USA (2020). https://doi.org/10.1145/3392063.3394400, https://doi.org/10.1145/3392063.3394400

[68] Rutledge, K., McDaniel, M., Teng, S., Hall, H., Ramroop, T., Sprout, E., Hunt, J., Boudreau, D., Costa, H.: State of the world's birds: taking the pulse of the planet (2012), https://education.nationalgeographic.org/resource/geocaching/, (accessed: 05.12.2023)

[69] Salazar, F.L., Nakajima, T., Alexandrova, T.: Visual novels: An methodology guideline for pervasive educational games that favors discernment. In: Park, J.J.J.H., Arabnia, H.R., Kim, C., Shi, W., Gil, J.M. (eds.) Grid and Pervasive Computing. pp. 234–243. Springer Berlin Heidelberg, Berlin, Heidelberg (2013)

[70] SEGA: Sonic the hedgehog classic (2019), https://play.google.com/store/apps/details?id=com.sega.sonic1px&hl=en_US&pli=1, (accessed: 07.04.2025)

[71] Stevenson, K.T., Szczytko, R.E., Carrier, S.J., and, M.N.P.: How outdoor science education can help girls stay engaged with science. International Journal of Science Education **43**(7), 1090–1111 (2021). https://doi.org/10.1080/09500693.2021.1900948

[72] Tan, W., Huang, C., Xiang, H.: Improving the scientific literacy of primary school students from the perspective of double reduction: practical inspiration. Salud, Ciencia y Tecnología - Serie de Conferencias **3**, 987 (06 2024). https://doi.org/10.56294/sctconf2024987

[73] Tek Sapo: 95% das crianças portuguesas com 10 anos já têm um smartphone (12 2021), https://tek.sapo.pt/noticias/negocios/artigos/95-das-criancas-portuguesas-com-10-anos-ja-tem-um-smartphone, (accessed: 22.11.2023)

[74] Tutkun, C.: The impact of augmented reality technology on children's development: Scoping review. In: Proceedings of the 7th International African Conference On Contemporary Scientific Research, Tripoli, Libya. pp. 15–16 (2024)

[75] Visit Madeira: Madeira natural park (2025), https://visitmadeira.com/en/what-to-do/nature-seekers/protected-areas/madeira-natural-park/, (accessed: 02.06.2025)

[76] Wu, M., Li, Z., Zhang, Z., Wang, Y.: Greencompass: Experiencing urban pocket time as playful nature connection through context-aware gamification. In: Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems. CHI EA '25, Association for Computing Machinery, New York, NY, USA (2025). https://doi.org/10.1145/3706599.3719811, https://doi.org/10.1145/3706599.3719811

[77] Yanez, R., Fees, B., Torquati, J.: Preschool children's biophilia and attitudes toward nature: The effect of personal experiences. International Journal of Early Childhood Environmental Education (01 2017)

[78] Zhang, Y., Huang, Z.: A board game hootopia: Biodiversity education through tangible and interactive narrative. In: Holloway-Attaway, L., Murray, J.T. (eds.) Interactive Storytelling. pp. 410–421. Springer Nature Switzerland, Cham (2023)

[79] Zimmerman, J., Forlizzi, J., Evenson, S.: Research through design as a method for interaction design research in hci. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. p. 493–502. CHI '07, Association for Computing Machinery,

New York, NY, USA (2007). https://doi.org/10.1145/1240624.1240704, https://doi.org/10.1145/1240624.1240704

[80] Zulfiqar, F., Raza, R., Khan, M., Arif, M., Alvi, A., Alam, T.: Augmented reality and its applications in education: A systematic survey. IEEE Access **PP**, 1–1 (01 2023). https://doi.org/10.1109/ACCESS.2023.3331218

A Ethics Committee Approval

This appendix section contains the formal ethics approval document provided by Madeira´s University's Ethics Committee. This document confirms that the research design and methodology were thoroughly reviewed and found to be in full compliance with all ethical guidelines for conducting research involving human participants.

The name of the final thesis was changed, due to already being used for a research paper with preliminary results that we previously submitted before the delivery of the thesis.

UNIVERSIDADE da MADEIRA
COMISSÃO DE ÉTICA

PARECER Nº 210/CEUMA/2025, DE 26 DE JUNHO

Sobre o pedido de apreciação pela Comissão de Ética da UMa do projeto de investigação: "Combining the potential of XR with interactive narratives to promote engagement between children and natural heritage."

A - RELATÓRIO

O pedido de apreciação do documento nº 210 de 2025 respeita ao es Combining the potential of XR with interactive narratives to promote engagement between children and natural heritage", submetido por Luís Francisco Coelho Fernandes, no âmbito de um Mestrado, sob a orientação da orientadora Professora Doutora Mara Dionisio, da Faculdade de Ciencias Exatas e Engenharias da Universidade da Madeira.

O pedido em análise está instruído com os seguintes documentos:

a) Formulário de pedido de parecer à CEUMa assinado;
b) Curriculum Vitae dos investigadores OU Ciência ID OU ORCID OU CNPq;
c) Parecer do Encarregado da Proteção de Dados da Universidade da Madeira favorável à realização do estudo;
d) Declaração das orientadoras científicas;
e) Declaração de aceitação do estudo por parte do Chefe de Divisão do Parque Ecológico do Funchal;
f) Declaração de aceitação do estudo por parte da Chefe da Unidade do CCIF do Município do Funchal;
g) Documento de informação ao participante e consentimento informado, livre e esclarecido para participação em estudos de investigação, seguindo a minuta da Universidade da Madeira ou de entidades creditadas;
h) Documento de guião de entrevista, sem identificação ou cabeçalho, com perguntas;
i) Protocolo do estudo;

O estudo tem início a 1 de julho de 2025 e fim 30 de julho de 2025, tem como objetivo geral: "Determinar se jogos educativos com narrativas interativas e realidade aumentada (RA) podem promover e motivar crianças de 9 a 12 anos a interagir com a natureza e aprender sobre ela em contextos educacionais formais e informais."

Trata-se de estudo experimental a ser aplicado em pelos menos cinco menores de idade, proficientes em português, recrutados por conveniência numa lógica de *"snowball sampling"*. As técnicas a serem utilizadas são entrevistas e notas de observação de campo. O consentimento informado segue a minuta da UMa aplicável a menores e garante a natureza voluntária a todo o tempo da participação e está assegurada a proteção dos dados recolhidos (cfr. concordância da Encarregada de Proteção de Dados da UMa).

A recolha de dados será realizada no Parque Ecológico do Funchal e a destruição dos dados será feita no fim de 2025. Os dados serão armazenados em pastas digitais de acesso restrito, apenas acessíveis aos membros da equipa de investigação do projeto. *Nada se diz sobre as notas de observação de campo.* Os eventuais custos poderão ser de transporte.

Em relação à compensação e custos, os investigadores assumem que a ""Os participantes serão beneficiados ao adquirir conhecimento sobre ameaças naturais, espécies em extinção e ações que podem tomar para ajudar." Não haverá retorno aos participantes, nem riscos associados.
A divulgação e disseminação dos resultados serão feitas pela publicação da própria dissertação de mestrado, em *open acess,* e em congressos.

B – QUESTÕES DE PROCEDIMENTOS ÉTICOS E DOCUMENTOS EM FALTA

Da análise de toda a documentação decorre a conformidade do processo com os procedimentos éticos da investigação.

C - CONCLUSÃO
A CEUMa deliberou aprovar, por unanimidade, tendo em conta o que está indicado no Bloco B deste parecer.

Relatora: Professora Doutora Liliana Rodrigues

A Presidente da CEUMa

Assinado por: **Liliana Maria Gonçalves Rodrigues de Góis**
Num. de Identificação: 10084399
Data: 2025.06.27 11:51:06+01'00'

CHAVE MÓVEL

Professora Doutora Liliana Rodrigues

B Informed Consent

The informed consent forms used in this study are included in this appendix. These documents were presented to all research participants and their legal guardians to ensure they were fully aware of the study's purpose, procedures, potential risks, and their right to withdraw at any time.

UNIVERSIDADE da MADEIRA

Consentimento Informado

Título do estudo: Combinando o potencial da Realidade Aumentada (AR) com narrativas interativas para promover o envolvimento entre crianças e património natural

Investigador principal: Luís Francisco Coelho Fernandes, Universidade da Madeira
2056219@student.uma.pt

Enquadramento:

Num mundo de crescente degradação ambiental, urge promover o cuidado com a natureza. A UNESCO defende que até 2025 a integração da educação ambiental seja um elemento essencial em todos os países, para contribuir ativamente para o bem-estar do planeta e adotar estilos de vida sustentáveis. Uma forma de combinar estes dois objetivos é promover o envolvimento em experiências baseadas na natureza, uma vez que estas têm sido amplamente associadas a resultados positivos notáveis, tanto para os indivíduos como para o planeta.

A Realidade Aumentada (RA) é uma tecnologia que apresenta a possibilidade de interação entre o mundo físico e o digital, facilitando a visualização de conteúdos mais complexos. Esta tecnologia pode ainda facilitar o papel de educadores e professores, motivar a aprendizagem ativa dos alunos nas escolas e ajudá-los na retenção e aprendizagem de diversos conteúdos.

Objetivo: Investigar a Realidade Aumentada em combinação com narrativas interativas para sensibilizar as crianças para a biodiversidade do Parque Ecológico do Funchal, promovendo assim a sua sustentabilidade.

Procedimento:

Com a intenção de analisar a eficácia de ferramentas tecnológicas no contexto de educação formal e informal, foi desenvolvida uma aplicação que combina a Realidade Aumentada e narrativas interativas, que levará os seus utilizadores a explorar a biodiversidade do Parque Ecológico do Funchal.

Neste âmbito, será pedido ao seu educando que interaja com um o jogo, a fim de explorar uma de duas histórias, sobre os mistérios do Parque Ecológico. A atividade será explicada de forma acessível às crianças. O seu educando poderá recusar-se a participar no estudo ou desistir do mesmo a qualquer momento, sem ter de apresentar alguma justificação.

Será ainda pedido ao seu educando para responder a alguns inquéritos e responder a uma pequena entrevista. Esta atividade terá uma duração de aproximadamente 30 minutos.

Riscos: Não existem riscos associados a esta experiência, sendo que esta é uma atividade semelhante à de uma visita de estudo.

Condições e financiamento: Esta declaração de consentimento será arquivada nas instalações do Interactive Technologies Institute e não será divulgada a terceiros. Durante o estudo serão recolhidos dados sobre todas as escolhas que o(a) seu(a) educando(a) fizer usando as aplicações disponibilizada com conteúdos relativos à Natureza e ao Parque Ecológico. Os resultados dos inquéritos, respostas às entrevistas, áudio e imagem destinam-se apenas a análise estatística. Os dados recolhidos só poderão ser divulgados em revistas, eventos científicos ou em contexto educativo. Cada participante será identificado através de um código aleatório, que não permitirá identificá-lo (a) a si ou ao(à) seu(a) educando(a) pessoalmente. Todos os dados recolhidos serão mantidos em anonimato e serão armazenados num servidor do Interactive Technology Institute (ITI), ao qual apenas os investigadores envolvidos neste estudo poderão aceder até ao final de 2025. Após o final de 2025, os dados recolhidos serão eliminados de todos os servidores, discos e dispositivos onde tenham sido armazenados. Apenas as pessoas diretamente envolvidas

no projeto terão acesso a estes dados, de forma a evitar a sua disseminação e garantir a sua integridade e eliminação futura.

Não existem custos nem compensações por participar neste estudo.

Anonimato e confidencialidade: A recolha e tratamento de dados pessoais, no âmbito do estudo em causa, está de acordo com a legislação em vigor, nomeadamente, a Lei nº. 58/2019 de 8 de agosto, que assegura a execução, na ordem jurídica nacional, do Regulamento Geral de Proteção de Dados (EU) 2016/679 do Parlamento e do Conselho, de 27 de abril de 2016, relativo à proteção das pessoas singulares no que diz respeito ao tratamento de dados pessoais e à livre circulação desses dados.

Além disso, quaisquer dados conseguidos através deste estudo, como pelas respostas a entrevistas ou notas do investigador, serão anonimizados com números de identificação aleatórios para cada participante, e será utilizada modificação de voz enquanto os resultados das entrevistas são transformados em texto.

Direitos: A qualquer momento o(a) Sr(a) responsável pela educação da criança poderá pedir para aceder aos dados do seu educando, bem como pedir para remover os seus dados da nossa base de dados ou até mesmo apresentar reclamação junto da CNPD (Comissão Nacional de Proteção de Dados) http://www.cnpd.pt/. Tem ainda o direito de retirar consentimento em qualquer altura, sem comprometer a licitude do tratamento efetuado com base no consentimento previamente dado. A recusa em participar ou interrupção da participação não resultará em qualquer penalização ou perda de eventuais benefícios ou direitos. O investigador principal poderá decidir, de forma fundamentada, interromper a participação do interveniente neste estudo. Mesmo neste caso, não haverá qualquer penalização ou perda de eventuais benefícios ou direitos. Se o interveniente tiver dúvidas sobre este estudo, desejar obter mais informações ou pretender interromper a sua participação no estudo, poderá entrar em contacto com o Investigador Principal (2056219@student.uma.pt). A informação de contacto está disponível no início da primeira página deste documento.

Menores: Os menores (indivíduos com idade inferior a 18 anos) não podem legalmente dar o consentimento para participar em estudos de investigação. O consentimento só pode ser dado pelo guardião do participante ou responsável legal.

Ao assinar este documento, você confirma que leu a informação acima descrita sobre este estudo, e que todas as suas perguntas foram respondidas. Mesmo assim, você poderá fazer perguntas adicionais a qualquer momento durante o estudo e mesmo após este ter terminado. Ao assinar este documento, você concorda que o seu filho participe neste estudo de investigação.

NOME DO MENOR: _____

_____ _____

ASSINATURA DO PAI/MÃE/RESPONSÁVEL LEGAL DATA

_____ _____

ASSINATURA DO INVESTIGADOR DATA

C Parque Ecológico's do Funchal Document of Approval

This appendix contains the official document of approval from the Parque Ecológico do Funchal. This letter formally grants permission to conduct the research study on-site, acknowledging the park's support for the project.

Município do Funchal

Declaração

Para os devidos efeitos, declara-se que o aluno Luís Francisco Coelho Fernandes, no âmbito do seu plano de trabalhos de mestrado, encontra-se a desenvolver um projeto de investigação científica, que visa a criação de um jogo educativo 3D, com recurso à realidade virtual, com o objetivo de promover o conhecimento e a sensibilização para a biodiversidade local.

Para a realização deste projeto, foi-lhe concedida autorização para frequentar e utilizar, com fins científicos e pedagógicos, a área do Percurso da Biodiversidade no Parque Ecológico do Funchal (PECOF).

Por ser verdade

Funchal, 28 de maio de 2025

João Miguel Nunes

Chefe de Divisão do Parque Ecológico do Funchal

D Eco Detectives:Trailer

This appendix contains the official trailer for the "Eco Detectives" [20] (See Fig.27) application. The video provides a brief, visual overview of the game's core mechanics, narrative, and user interface. It is included as a supplemental material to demonstrate the project's interactive and aesthetic components.

`https://youtu.be/mW3CMWDXi_U?si=7J9D7wexy6H4WRf6`

Figure. 27: Eco Detectives Youtube trailer screenshot