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Fostering Climate Change Awareness
Harnessing Adult-Child Interactions in an Educational Game

MASTER DISSERTATION

Joana Filipa Gomes Spínola
MASTER IN INFORMATICS ENGINEERING

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Joana Filipa Gomes Spínola
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SUPERVISOR
Mara Sofia Gomes Dionísio

CO-SUPERVISOR
Paulo Alexandre Câmara Bala

Faculty of Exact Sciences and Engineering

Master of Science Degree in Informatics Engineering

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Joana Filipa Gomes Spínola

Supervised by:

Mara Sofia Gomes Dionísio

Paulo Alexandre Câmara Bala

Constituição do júri de provas públicas:

Professora Karolina Baras, Presidente

Professor Paulo Alexandre Câmara Bala, Vogal

Professora Ana Marta Galvão Ferreira, Vogal

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Resumo

À medida que as alterações climáticas tornam-se uma preocupação crescente, métodos eficazes de educação ambiental são essenciais para promover a consciencialização e ação. Uma das formas de alcançar esse objetivo é através dos jogos educacionais; em particular, identificámos uma oportunidade fundamental na interação entre adultos e crianças para estimular discussões sobre sustentabilidade e alterações climáticas. Assim, este trabalho apresenta o design, desenvolvimento e avaliação de *Mystiria*, um jogo sério colaborativo concebido para facilitar interações significativas entre adultos e crianças, ao mesmo tempo que sensibiliza para a sustentabilidade e alterações climáticas. Através de três mini-jogos assimétricos - focados na gestão de água, eletricidade e reciclagem - o jogo promove trabalho em equipa e comunicação num ambiente cativante e divertido.

O contexto do jogo foi adaptado à Ilha da Madeira, uma vez que investigação prévia sugere que a incorporação de um contexto local aumenta a probabilidade da compreensão do tema. O jogo foi avaliado por crianças (6 - 10 anos) - considerada uma idade ideal para a aprendizagem de conceitos importantes - e adultos (pais). Através de uma colaboração com a Divisão da Conservação da Natureza e Alterações Climáticas do Funchal, o protótipo será posteriormente avaliado por profissionais das áreas de educação e sustentabilidade, com a possibilidade de ser integrado no currículo escolar.

Os resultados da avaliação indicam que os componentes assimétricos de jogo - onde cada jogador desempenha tarefas distintas, mas interligadas - contribuíram significativamente para o envolvimento e a diversão dos participantes. Os jogadores reportaram que a necessidade de comunicar para serem bem sucedidos melhorou a colaboração e transferência de conhecimento intergeracional. Adicionalmente, com os questionários e interações promovidas pelas narrativas, o jogo revelou-se eficaz em promover discussões sobre sustentabilidade. Este estudo destaca a eficácia de jogos sérios colaborativos em promover diálogo intergeracional sobre sustentabilidade e alterações climáticas, demonstrando o potencial destes jogos para reforçar a educação ambiental.

Keywords: Interação Adulto-Criança · Educação sobre Alterações Climáticas · Sustentabilidade · Comunicação e Colaboração · Jogo Assimétrico

Abstract

As climate change becomes an increasing concern, effective environmental education methods are essential to bring awareness and action. One of the ways to do so is through educational games; in particular, we have identified a key opportunity for leveraging adult-child interactions to foster discussions of sustainability and climate change. As such, this work presents the design, development and evaluation of *Mystiria*, a collaborative serious game meant to facilitate meaningful interactions between adults and children while raising awareness about sustainability and climate change. Through three asymmetric mini-games - focused on water management, electricity and recycling - the game promotes teamwork and communication in an engaging and fun environment.

The game's context is tailored to Madeira Island, as previous research suggests that incorporating local context has better chances of increasing the player's understanding on the topic. The game has been evaluated by children (6 - 10 years old) - considered an optimal age for learning important concepts - and adults (parents). Through a collaboration with the Divisão da Conservação da Natureza e Alterações Climáticas of Funchal, the prototype will later be evaluated by professionals in the fields of education and sustainability, with the potential of being integrated in the educational curriculum for schools.

Findings from the evaluation indicate that the asymmetric components of the gameplay - where each player has distinct yet correlated tasks - significantly contributed to user engagement and enjoyment. Participants reported that the required communication in order to succeed enhanced the collaboration and intergenerational knowledge transfer. Additionally, during quizzes and narrative-driven interactions, the game facilitated discussions on sustainability.

This research highlights the effectiveness of collaborative serious games in fostering intergenerational discussions on sustainability and climate change, demonstrating the potential of these games to enhance environmental education.

Keywords: Adult-Child Interaction · Climate Change Education · Sustainability · Communication and Collaboration · Asymmetric Play

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Table of Contents

List of Figures

List of Tables

Lista de Acrónimos

ACI Adult-Child Interactions

AR Augmented Reality

GEQ Game Experience Questionnaire

IDC Interaction Design Children

IPCC Intergovernmental Panel on Climate Change

MVC Model-View-Controller

NEP New Environmental Paradigm

RPC Remote Procedure Call

RtD Research Through Design

UI User Interface

UML Unified Modelling Language

UNFCCC United Nations Framework Convention on Climate Change

VR Virtual Reality

1 Introduction

Climate change is one of the most pressing global challenges, with greenhouse gas emissions being the cause of increased global temperatures, rising sea levels and extreme weather events [3]. Projections suggest that by 2030, global temperatures will exceed a 1.5^{o}C rise above pre-industrial levels, with projections of a 2.5^{o}C increase by 2100 [3]. Although these numbers might seem small, they can trigger catastrophic changes to our ecosystems and human societies. Even a 1.5^{o}C increase is associated with drastic changes, including rising sea levels, more frequent and intense heat waves and disruptions to food and water systems. This underlines the urgency of taking immediate climate change action now to limit temperature rises. The United Nations (UN) 2030 Agenda for Sustainable Development [4] encompasses 17 Sustainable Development Goals [5], with Goal 13 [5], focusing on urgent action to combat climate change and its impacts.

Within the intricate connections of our society, the delicate balance between children's well-being and sustainability emerges as a pivotal issue which influences the trajectory of the future. Climate change is not just a threat to the environment and economy, but also jeopardizes children's rights, health, and overall well-being [6, 7]. Children are the most vulnerable to the impacts of unsustainable living, with specific harms arising because of their physical and cognitive vulnerabilities, as well as developmental dependencies [8, 9]. They are on the front line of the impacts of climate change, facing a world shaped by an increase in temperatures, environmental shifts [10], resource scarcity, natural disasters and an increase in diseases [8].

In recent years, young people have emerged as key advocates for climate action, exemplified by figures such as Greta Thunberg [11], highlighting their commitment to environmental sustainability and their role in shaping the future. However, while the engagement of the younger population is increasing, climate action still remains largely dependent on adults who are currently making decisions and implementing policies. This raises a crucial point: for long-term sustainable solutions, it is essential to foster collaboration between adults and children. Moreover, involving children alongside adults in educational and practical activities regarding climate change and sustainability cultivates a sense of shared responsibility.

Given children's capability of taking concrete action against climate change, it is crucial that we introduce these concepts at an early age. Despite these challenges, children do not need to become

victims, as the combination of early childhood education with serious games presents a potential solution to tackle these issues [12]. Educating the next generations plays a fundamental role in the transition towards more sustainable societies [13]. It is advantageous to target younger age groups, as they are in the process of developing several habits that are already well-established in adults (e.g., the purchase and consumption of plastic products) [14].

Serious games have emerged as a promising tool for climate change education, as these can create an environment in which users are motivated to engage with material related to the area where behaviour change is desirable [15]. The choice of using games, instead of traditional teaching methods, is because research has shown they are more persuasive [16] and gamification leads to longer-term psychological engagement [17]. Serious games designed for the interaction between adults and children offer a unique opportunity for collaborative learning and the exchange of perspectives and knowledge between generations [18]. Without these games, the potential for fostering shared values and a collective commitment to sustainable practices are underutilized. This type of interaction in games encourages joint problem-solving and decision-making, while also elevating the understanding of environmental issues and strengthening the bond between adults and children. However, existing games on the market very rarely require any type of interaction between adults and children, thus creating a notable gap in environmental education – this creates a research opportunity in collaborative climate change education.

With climate change increasingly threatening ecosystems, human lives and economic stability [3,19,20], innovative solutions for environmental education are paramount. Although numerous initiatives focus on raising awareness [21, 22, 23, 24, 25, 26, 27], they often target these two groups separately, overlooking the value of fostering collaboration and intergenerational knowledge transfer.

Inspired by the potential of adult-children discussion on sustainability concepts and in order to bridge this gap, we introduce *Mystiria*, a novel serious game which we designed and developed to facilitate meaningful interactions between adults and children while raising awareness about sustainability and climate change. Unlike traditional games that focus on individual learning, *Mystiria* leverages asymmetric play mechanics, where each player has unique responsibilities that require communication, collaboration and shared decision-making. *Mystiria* is specifically tailored to Madeira Island as Rowntree et al. [28] suggest that simulations that are grounded in the local

context, instead of a global approach, may offer the greatest potential for changing beliefs and behaviours. Research has shown that teaching about global climate change and global warming is didactically ineffective, so instead, we want to educate them about their local situation [29]. We believe that this will instil proactive behaviour in children and adults as they witness changes in their immediate surroundings and how it will affect their daily life. By introducing the interaction between adults and children, we hope to promote dialogue and shared learning experiences. Simultaneously, we aim to inspire children to take initiative in making positive changes for their future.

The methodology followed in this dissertation is based on a combination of research through design, user-centred design principles, and mixed-methods data collection and was guided by the following research questions:

- **RQ1:** *What elements of the educational game contribute to user engagement and enjoyment, particularly within the context of climate change awareness?*

- **RQ2:** *How does the interaction between adult and child promote discussion and/or knowledge transfer about climate change awareness?*

By exploring these research questions, our evaluation suggested that *Mystiria* has the potential to promote adult-child interactions and collaboration, thereby supporting engagement with sustainable behaviours. The game's gameplay design encouraged communication between players, particularly during the mini-games. Our findings indicate that the shared gameplay experience enhanced the bond between players, allowing for intergenerational knowledge exchange. While *Mystiria* showed promise in fostering engagement and understanding of the topics, further refinements could ensure smoother gameplay and better communication between players. This dissertation contributes to the existing body of work in serious games.

Regarding our contributions, both a Work-in-Progress [1] and a Demonstration [2] paper have been accepted to the Interaction Design and Children (IDC) conference[3].

[1] https://doi.org/10.1145/3713043.3731501
[2] https://doi.org/10.1145/3713043.3731479
[3] https://idc.acm.org/2025/

1.1 Dissertation Structure

This master's dissertation begins with the **Literature Review** chapter, where the existing research on topics such as educational games, climate change awareness, asymmetric play and designing for children are reviewed to provide a foundation for the project. Next, the **Foundations of Game Development** chapter explains the research approach used to design and develop the game, focusing on the chosen methodology, stakeholders, initial game concept, personas and experimenting with technologies. The **Game Design** answers the "what" of the project, as it provides the conceptualization of the game, its narrative and gameplay. Following this, we have the **System Architecture and Design**, that addresses the "how". In this chapter, we will delve into the technical implementation, including system requirements, system architecture, use cases and UML diagrams. The **Implementation** chapter follows, outlining the actual development process and the pilot test. The **User Evaluation** presents the study design, protocol and measures, data analysis, quantitative and qualitative results. To conclude, there are the **Discussion** and **Conclusion** chapters.

2 Literature Review

In this chapter, we provide context for topics central to this investigation, delving into important concepts and existing gaps in the literature. This theoretical background chapter acts as a guide to offer a comprehensive understanding of the key concepts that shape our research.

Our aim is to highlight what is already known in the field, while identifying areas that remain underdeveloped. By critically examining previous literature, we can discern the progress made to date and uncover gaps, hence establishing a solid foundation for our research.

This chapter encompasses a review of critical concepts and studies related to environmental education for children, sustainability and climate change, game design for younger audiences, and the role of serious games and technology in fostering awareness and engagement.

2.1 Sustainability & Climate Change

Sustainability is defined as the interaction between humans and the environment and with other human beings in order to achieve environmental, social and economic advantages [30].

There are three pillars of sustainability [31]:

- **Environmental sustainability**: Focuses on minimising the impact of human activities on the environment. Involves practices that aim to conserve natural resources, reduce pollution and protect ecosystems to ensure the overall health of the planet. Environmental sustainability should be essential for everyone's personal values [32].
- **Social sustainability**: Involves creating fair and just societies, emphasizing social justice, human rights, community development and the overall well-being.
- **Economic sustainability**: Establishing systems that ensure a stable and prosperous economy in the long term. This includes fostering innovation, creating sustainable job opportunities, and managing resources responsibly to ensure future economic resilience.

Sustainable development [31] is defined as meeting the needs of the present without compromising the capacity of future generations to meet their own needs [8, 33]. However, climate change threatens this principle, as it is characterized by significant and lasting alterations in climate patterns, primarily induced by the emission of greenhouse gases from both natural and human sources.

While the Earth's system possesses inherent self-regulating mechanisms, anthropogenic emissions are overwhelming these natural processes, leading to environmental instability [10].

According to a recent report from the Intergovernmental Panel on Climate Change (IPCC), anthropogenic activities have already caused a global temperature increase of approximately 1ºC above pre-industrial levels [3]. These increases in temperature will persist and intensify, leading to irreversible damage, unless people's view on sustainability and climate action change. Given that children are at a formative stage in developing their attitudes, values and habits, they represent a crucial demographic for instilling long-term sustainable behaviours. Educating children about sustainable practices at an early age may increase the likelihood of long-term commitment to environmentally responsible actions, leading to positive changes [34].

Global warming, a prominent aspect related to climate change, poses a significant and direct risk to children worldwide. The impacts of rising temperatures, changing weather patterns and environmental degradation have deep consequences that affect children's health, safety, education and overall development [3, 35]. For instance, coral reefs (which are crucial for marine biodiversity and coastal protection) face a 70-90% loss at 1.5ºC and near-total collapse at 2ºC global warming. At 2.5ºC, the risks escalate even further, with widespread loss of biodiversity, irreversible changes to ecosystems, and significant changes to global agriculture, public health and water resources [3]. Given the disproportionate impact on younger generations, urgent and aggressive climate action is necessary to mitigate these risks and ensure a sustainable future.

2.1.1 Madeira Island

Island environments exhibit a heightened sensitivity to externally induced changes. The main reason is the limited space available on most islands, which hinders the implementation of adaptation measures that involve relocation of resources and activities [36]. Island systems are particularly susceptible to climate change, which is anticipated to induce shifts in temperature, rainfall and/or sea levels [37]. The analysis of climate change scenarios and impacts on small islands is difficult, due their coastal features, unique landscapes and climate [36]. Due to this difficulty, Santos et al. [36] have created a specific model for the Madeira and Azores islands. In their study, they found that temperatures are rising at 0.53ºC per decade for the maximum temperature and 0.66ºC for the minimum, in Funchal (Madeira), since the early 1970s. In future scenarios, the loss of annual

precipitation varies between 20% and 35% [36]. These numbers are very alarming since Madeira Island relies heavily on gathering water in reservoirs. With this kind of fall in water supply, the island becomes more vulnerable to episodes of drought by the end of the 21st century, leading to subsequent impacts on water resources, local flora and agriculture. By the end of the 21st century, Madeira climate is predicted to become hotter and drier, having significant impacts on the natural ecosystems (namely a large area of protected humid forest called Laurissilva, that is protected by UNESCO and is part of the world heritage), hydroelectricity production and the capture of precipitation, which inherently feeds small rivers and ground water systems [36].

The impacts of these changes extend beyond the environment, posing a significant risk to human health, particularly for children. The following key areas highlight the potential effects of climate change on more vulnerable populations, focusing on children [3].

- **Health risks**
  - **Heat-related illnesses**: The increase in temperatures can lead to more frequent and intense heatwaves, which prompts dehydration and heatstroke.
  - **Vector-borne diseases**: With changes occurring in temperature and precipitation patterns, there is a potential influence in the distribution of disease-carrying vectors such as mosquitoes. This, in turn, can contribute to a heightened transmission of diseases, like malaria and dengue, which particularly impact children.
- **Food insecurity**: Changes in climate can disrupt agricultural patterns, leading to crop failures and food shortages. Children part of vulnerable communities may face malnutrition and stunted growth due to lack of nutrients.
- **Water scarcity**: As the precipitation patterns change, droughts and water scarcity will be more frequent. The lack of access to clean water and sanitation poses health risks for children, likely increasing the chances of catching waterborne diseases.
- **Extreme weather events**: With more frequent and severe extreme weather events (hurricanes, floods, wildfires, etc.) families can be displaced and expose children to trauma. This displacement will cause disruptions in multiple aspects of their lives, such as social stability, education and development.

- **Air pollution**: Children, with their developing respiratory systems, are particularly vulnerable to respiratory issues like asthma and other respiratory infections, caused by pollutants emitted by the burning of fossil fuels (major contributor of global warming).
- **Educational disruptions**: Extreme weather events and environmental disruptions can lead to the closure of schools, disrupting children's education and hindering their long-term development.
- **Psychological and mental health impacts**: The uncertainty and disruptions caused by climate change can contribute to children's anxiety and stress, affecting their mental health severely.
- **Disproportion of the impact on vulnerable communities**: Children in low-income communities are often more vulnerable to the impact of global warming due to the limited resources and inadequate infrastructures.

2.1.2 Environmental Education for Children

Children, being the leaders of tomorrow [34], have a very important role in climate action, so early childhood education is expected to have a direct impact on the future of the environment. Consequently, early childhood education plays a crucial role in fostering resilience and developing essential skills in children. This will empower them to become active and informed citizens capable of making valuable contributions to lead healthy and sustainable lifestyles [8]. Early childhood interventions have also proven to be the most effective when compared to spending money on programs at later stages of children's development [13], as it is when children develop attitudes and behaviours that contribute to a sustainable future for everyone [33, 38]. These interventions hold a significant importance, as complex understanding of scientific concepts are formed early in life through children's everyday experiences and interactions with those around them [39].

When children possess a connection to nature, an understanding of fairness, a sense of individuality within a group, and the ability to negotiate agreements, the essential prerequisites for sustainability education are fulfilled [13]. By teaching children how to appreciate the natural environment and love its beauty, it will lead to them wanting to protect the environment naturally [29].

Initiating environmental education with local examples is didactically more effective than teaching about broad topics such as global warming and climate change. With a localized approach,

children are more susceptible to want to make changes, as those will be more immediate and directly relevant to children's daily lives [29].

Moreover, recognizing young children's distinctive viewpoints and untapped potential is very important. Their capacity to assimilate information, form attitudes and participate in discussions with peers and family holds the potential to enhance awareness and promote positive behavioural changes within communities [40].

For children, social learning and following a role model can have a very positive impact on their actions, so a parent's actions towards climate action and sustainability will influence their children. According to Yıldız et al. [29], parents are the most effective role models for children, so they should also be encouraged to develop sustainability-oriented practices. By developing a game that uses the interaction between adults and children, we are tapping into the potential influence of an adult role model. This intentional approach, not only enhances the gaming experience but also recognises the importance that positive adult interactions have on children.

Moreover, in order to have effective communication with children about challenging topics, the approach needs to take into account age-appropriate language, positive framing and the use of storytelling. Using language tailored to their age level, framing discussions in a positive light, and creating compelling narratives can enhance engagement and understanding, making it easier for children to comprehend and navigate complex subjects with sensitivity and clarity [41, 42]. Storytelling, in particular, helps make abstract issues emotionally relatable for younger audiences, and effective communication must be tailored to their emotional and cognitive needs [43]. These insights informed the design of Mystiria, which uses hopeful narratives and cooperative play to foster emotional engagement and intergenerational dialogue, aligning with our approach.

2.2 Serious Games

There are many definitions of serious games [44], but according to Alvarez [45], it "is to invite the user to interact with a data-processing application whose intention is to combine at the same time teaching, training, communication, or information aspects, with ludic mechanisms based on video game. The purpose of such an association is thus to give attractive shapes or plots (Game) to didactic contents (Serious)."

The positive learning outcome achieved with serious games, makes them promising in an educational context [46,47], as they include all aspects of education (teaching, training and informing) and can be used at all ages [48]. Serious games do not have entertainment as their main purpose [49, 50], so they offer unique opportunities for sustainability learning [31]. They allow the creation of virtual representations of complex scenarios that can be explored and analysed by learners to highlight the dynamics and interactions between the elements and actors involved. Players can have a better understanding of the consequences of their actions in both a global scale and large time span in a safe scenario, which does not actually damage the environment [31, 51]. Serious games possess very useful advantages, which include:

- Allowing the experience of situations that are impossible in the real world, due to safety, costs, time, etc. [48];
- Involving the user in the educational process can have a positive influence in the development of a number of different skills (analytical and spatial skills, strategic thinking, insight, learning and memory capabilities, psycho motor skills, etc.) [52];
- Enabling the improvement of self-monitoring, problem recognition and solving, decision making, improved short-term and long-term memory and heightened social skills, such as collaboration, negotiation and shared decision making [52].

Sustainability serious games must provide an experience in which entertainment and instructions are seamlessly integrated [31]. This cohesion is vital for engaging and educating children effectively. By integrating entertainment, we can ensure that users will remain captivated and motivated throughout gameplay [53]. Simultaneously, the instructional component woven into the game conveys valuable knowledge and insights regarding sustainability. The integration of these elements not only creates an experience that captivates users, but also fosters an understanding of sustainable behaviours and encourages their practice.

2.2.1 Designing and Developing Serious Games

Designing and developing successful serious games requires the thoughtful consideration of multiple factors to guarantee the effective accomplishment of their educational goals. If the game is purely educational, the user will lose interest, hence a good-story with a progressive storyline, structure, characters and scenarios should be included [54].

For serious games to be able to fulfil their purpose and be successful, the design and development phases should follow the subsequent guidelines [55]:

- **User centred software**: To develop an effective serious game, it is crucial to possess a thorough comprehension of the user experience that players will encounter during gameplay.
- **Multimodal serious games**: For a serious game to be convincing, multimodalities could be incorporated (e.g. haptic feedback). Integrating alternative interaction methods, such as full and partial body capture, gesture recognition, and wearable devices, has the potential to enrich immersion in digital gaming, and as a result it will support cognitive processes [56].
- **Social well-being**: Encouraging a sense of virtual presence or a connection that enhances social well-being in real life.
- **Adaptive gaming**: A serious game should adapt according to the player's particular needs, capabilities and interests.
- **Standardization of evaluation**: Evaluation is essential to measure the effectiveness of a game and to allow improvements of these games by pointing out their weaknesses.
- **Sensory-based simulations**: Serious games can be created using real world sensory data in order to accurately reconstruct a scenario.

For a serious game to be successful, in the design of the game, there must be a balance between the entertainment element and the main purpose of the game, which, in our case, is teaching about climate change and sustainable practices.

2.2.2 Games for Sustainability

From the review of multiple studies, conclusions have been drawn that support that simulation games help students increase their awareness of real world issues [57]. Subsequently, we broadened our scope to explore other games that share a purpose or thematic alignment with our research. To find relevant games for our study, we conducted an online search focused on games that promote sustainability and climate change awareness. We explored various game platforms and repositories, specifically looking for free games that address these critical environmental themes. From this search, we identified the following games:

- **Bleached AZ**: This game promotes ocean health awareness and motivates players to actively contribute to environmental conservation. It has funny characters presenting environmental issues such as coral bleaching, pollution and over-fishing. The aim of the game is to remove the plastic and fishing lines without killing the fish or the corals. Overall, this game is entertaining but also educational as it will show some facts throughout gameplay [58].
- **Working with water**: It is a turn-based web game that teaches players about water management. In the game, the need for clean drinking water increases as the community grows and the player is responsible for building new infrastructures to meet such demand. There are challenges (ex: drought, algae bloom) that need to be overcome by completing projects (e.g. maintenance, building new infrastructures), all with a specific learning outcome [59].
- **Super Energy Apocalypse Recycled**: The mechanics of this game are very different from the others. The goal is to build a base and defend it against zombies, which are a metaphor for trash [60].

2.2.3 Intergenerational Learning and Asymmetric Play

Intergenerational learning represents a dynamic exchange of knowledge, values and skills between different generations [61]. Serious games have increasingly been recognized for their potential to facilitate this way of learning, as highlighted in preceding studies [62, 63]. Previous research in the field of intergenerational interaction has explored multiple contexts, such as designing an interactive installation in a museum for musical play [64]; creating prototype to improve remote communication between adult children and their parents in China [65]; adult-child play using a tablet [66]; exploring the benefits of parents and children cooking together [67] and others [68, 69, 70, 71], but, to the best of our knowledge, no prior work has designed this type of interaction regarding sustainability and climate change.

In the available literature, asymmetric play has proven to encourage collaboration and engagement between players with varying skill levels, abilities and roles [72]. As demonstrated by Harris et al. [73], asymmetric play increases social presence, perceptions of connectedness, immersion, behavioural engagement and understanding. Pais et al. [74] developed an asynchronous asymmetric game for family play, in which the players had two very distinct roles. By assigning different roles to players, the game promotes interdependence by requiring participants to work together

to achieve a common goal, despite having different responsibilities. Chen et al. [75] investigate how different control mechanisms in an asymmetric collaborative game are able to prompt social interactions amongst users. Nonetheless, these works have primarily focused on generalized topics, and not necessarily being applied to a serious games with a specific topic like sustainability.

2.3 Designing for Children

While there are many theories regarding child development, Jean Piaget's contributions [76] are the most popular and widely adopted. One of these contributions, the identification of four cognitive stages [76], can be used to understand children's cognitive abilities (and consequently help design games/experiences in accordance to their skills). These stages are:

- **Sensorimotor Stage** (0 - 2 years old): Focused on object permanence and the development of sensory and motor skills;
- **Preoperational Stage** (2 - 7 years): Characterized by the emergence of symbolic thought;
- **Concrete Operational Stage** (7 - 11 years): Marked by the ability to think logically;
- **Formal Operational Stage** (11 years and older): Defined by the capacity for symbolic reasoning.

Piaget's theory also emphasizes the active role of children in constructing their understanding of the world through interaction with the environment [77]. As such, designing for children should account for their developmental stages, interests and educational needs; it is also important to note that children's skills develop quickly, so these changes have repercussions in game development.

When designing for children, several aspects have to be considered in order to create engaging, developmentally appropriate, and enjoyable experiences [1]:

- **Challenge**: Children thrive in challenge and conflict, so in games, the added challenge, makes the accomplishment more significant for them but also enhances the overall excitement and enjoyment of the game. "Conflict play" also helps young children develop skills such as predicting how others are likely to react to their behaviour, controlling their emotions, communicating clearly, seeing other people's point of view and creatively resolving disagreements.
- **Feedback**: Children like to be rewarded with everything they do, so visual and auditory feedback is a must.

- **Change**: The age range when designing a game is very important. If it is too large, there are too many changes between the possible users, so the game will not be enjoyed by all, unless all their needs are catered to, and this is very hard to do.

- **Consistency**: The design patterns need to remain consistent. Elements that get in the way, animate spontaneously or do not contribute to the overall goal can frustrate children. It is also important to distinguish between what is interactive or not, because if everything in the screen moves, is brightly coloured or makes noise in the same level, children will get too distracted.

- **Purpose**: The game's purpose should be evident right from the start. Clear communication about what the game is and how it works ensures that children can understand its goals and can engage effectively.

- **Surprise**: While maintaining consistency, the game should include delightful experiences that align with children's expectations. A balance between predictability and novelty keeps the experience fresh and engaging.

- **Easter eggs**: Small, unexpected rewards or interactions, such as hidden features or playful elements, can create moments of joy and deepen children's connection to the game.

For this work, the focus is on children aged 6-10 years old (primary schoolers), a developmental stage where they begin to read, reason and develop a more complex understanding of the world around them. This is a critical period in forming attitudes, values and behaviours, as children are increasingly capable of forming logical connections and understanding cause-and-effect relationships [2]. By introducing environmental concepts and fostering awareness during this formative phase, there can be a lasting impact on their perspective towards nature and sustainability.

Table 1 presents expected developmental characteristics for this age group and suggests design strategies to accommodate them [1].

When designing games, it is crucial that the initial levels have simplicity, to give a gentle introduction. Nevertheless, as the game progresses, the challenge should gradually escalate to maintain engagement and foster skill development. Despite the increasing difficulty, it is essential to balance the experience, ensuring that children continually experience a sense of achievement and positive progression [78]. It is also important to provide them with options and choices so they

Characteristics	**Design implications**
Focused but seek more challenge	Children in this age group can focus on tasks, but may seek increasingly challenging goals. Progression systems like "levelling up", continued achievement and more complex tasks need to be incorporated to keep players engaged.
Prefer a balance between upfront knowledge and exploration	The objective of the game, what they will be doing and why needs to be clearly defined at the beginning of the game, otherwise children will lose interest. This applies to children aged 6-8. However, for older children (8-10 years old), while they still appreciate knowing what to expect, they are increasingly drawn to exploratory elements that allow them to discover and experiment.
Comprehend and acknowledge the idea of permanence	Children will want to return to an experience and continue where they left off, so they need to be able to save, store and share the things they do, particularly high scores.
Strong sense of rules and fairness	They are very focused on following rules so a set of clear, easy-to-follow rules are needed. Nevertheless, children still need to interpret and expand on these.
Prefer quantity over quality	Instead of being the best, children prefer experiences that allow them to gather and collect, so basic gamification strategies such as awards, badges are needed.
Are starting to feel scared, suspicious or distrustful of those they do not know	Social interaction should not be the focus, because children at this age start to become hesitant about meeting new people and trying new things.

Table 1: Characteristics and their Implications of Children Aged 6-10 [1, 2]

feel empowered and in control. One way of accomplishing this goal, is to have a reward system with badges or bonuses [78].

Games can harness visual communication, leading to three potential side effects [79, 80]. One of the side effects is on the **cognitive** spectrum, as the information available increases, there is a reduction in the cognitive workload, clarifying certain patterns of value and identifying relationships. The second is **affective**, as emotional responses can be immediately triggered by the displayed elements. Lastly, there are **behavioural** effects, as visual communications are capable of influencing attitudes and behaviours of the players.

In regards to learning about the environment, studies suggest that games are more persuasive than traditional learning methods [81], and simulation games can help students increase their awareness of real world issues [34]. According to Mustafee et al. [82], games have the potential to increase comprehension of environmental issues and sustainable strategies. For children, whose learning experiences are often enriched through interactive and enjoyable activities, digital games are an effective learning tool. This educational tool captures the interest of the player, but also empowers them to become environmentally conscious individuals capable of making informed sustainable decisions [83].

To enhance the experience and maximize enjoyment, games should include motivational elements [53]. Ensuring player enjoyment is essential, as it fuels continued game participation, thereby enhancing their expertise about sustainability [51].

Based on the cognitive development stages by Piaget, Fisher was able to conclude that children aged 6-8 are increasingly able to strategize and keep multiple goals in mind, leading to their ability to play more complex games. They are also able to switch tasks and keep multiple rules in mind [2].

The main challenge observed when designing a game for a children's audience is the diverse range of abilities of any given target audience [2]. Children in the same age group can display significant differences in cognitive, motor and emotional development. When designing games for children, these differences must be considered to ensure that the game can be both enjoyable and educational across a wide range of abilities and developmental stages. Another aspect to remember when designing for children, is to design for accidental or quick success and ease them into the more challenging parts [2]. This is very important as children are quick to put down an experience

that is too difficult to confusing to use. The child should be able to get into the gameplay straight away.

2.4 Game Engines

This section highlights the main attributes and differences for three different game engines (Unity, Unreal Engine and Godot), and the subsequent choice made. The selection involved not only the performance considerations for each platform but also each platform's distinctive features. Based on documentation and information available on the engines' official websites, Table 2 presents a detailed comparison of the game engines, allowing for a clear identification of their differences. From the comparison, Unity was chosen as it grants the versatility to create games that can be seamlessly transferred to different platforms, like web browsers or PCs whenever the necessity arises.

Aspect	**Unity**	**Unreal Engine**	**Godot**
Programming Language	C#, C++	C++ and Blueprints (Visual Scripting)	GDScript (similar to Python)
Community Support	Large and Active	Strong Community	Growing Community
Graphics Capabilities	Versatile for 2D and 3D games	High-end Graphics	Balanced Features
Platform Support	Extensive (PC, mobile, console, AR/VR)	Broad Platform Support	Still expanding (PC, mobile, web)
Learning Curve	Beginner-Friendly	Moderate to Steep	Beginner-Friendly
Assets	Robust Asset Store	Marketplace	Growing Asset Library
Visual Scripting	Yes (Unity Visual Scripting)	Yes (Blueprints)	Yes (GDScript, visual scripting)
Graphics Rendering Quality	Good	Excellent	Good
Performance Optimization	Requires manual optimization for some cases	Advanced optimization tools	Efficient performance out of the box
Platform Stability	Stable with frequent updates	Stable with regular updates	Stable with consistent updates
Documentation Quality	Extensive and well-documented	Comprehensive documentation	Improving documentation
Cost of Development	Generally affordable	Can be higher due to royalty fees	Open-source, no royalty fees

Table 2: Detailed Comparison of Unity, Unreal Engine, and Godot

2.5 Discussion

In conclusion, the literature review conducted has offered valuable insights into the diverse spectrum of serious games and sustainability-focused games. The analysis conducted on serious games emphasises their importance and potential in learning contexts, particularly when addressing sustainability and climate change issues. The advantages of serious games, ranging from experiential learning opportunities to improvement of skills, makes them effective learning tools.

Furthermore, the exploration of specific games that target sustainability topics, allowed us to assess the varied approaches. From ocean health awareness in "Bleached AZ" to water management in "Working with water", these games display the potential there is when combining entertainment with educational objectives.

While there is a growing body of literature exploring the intersection of educational games and climate change awareness, a notable gap exists in games designed to leverage the interaction between adults and children for the explicit purpose of promoting climate change awareness. The existing research tends to focus primarily on individual experiences or generalized educational games that do not approach difficult topics. Integrating prompts that stimulate discussions on challenging topics into an educational game that harnesses adult-child interaction could help bridge the existing gap in the literature.

The research questions address critical gaps found in the literature review and have a chance to offer valuable opportunities for advancing serious games in sustainability and climate change education. As seen on Chapter 1 - Introduction, RQ1 explores what elements of the educational games contribute to user engagement and enjoyment, particularly in the context of climate change awareness, reflecting the literature review's insights into optimizing serious games design by balancing impactful learning with entertainment. RQ2 investigates the unique role of Adult-Child Interactions (ACI) during gameplay in order to promote discussion and knowledge transfer, directly addressing the lack of focus on intergenerational collaboration in existing studies. By answering these research questions, this study not only seeks to enhance our understanding of engagement and collaboration between adults and children in serious games, but also aims to provide a valuable framework for designing future educational games that combine entertainment with impactful learning experiences.

The choice of Unity as the game engine, further aligns with the project's goals, by offering a beginner-friendly interface, with extensive community support. Unity's cross-platform capabilities also offer the potential to maximize the reach and impact of such games.

3 Foundations of Game Development

This chapter presents the research methodology used in the development and evaluation of Mystiria, detailing the iterative prototyping process leading to the final version of the game. We adopted a Research Through Design (RtD) methodology, in which the designed artifact will serve as both the means of investigation and the research outcome. This approach involves working directly with design, prototyping and testing as a means to explore and validate theories, concepts, and ideas. Through this process new understanding is generated, becoming a form of knowledge production in itself [84].

Iterative prototyping played a central role, as it allowed us to continuously refine and evaluate the game design throughout multiple development stages. This ensured that the final product aligned with our objectives and effectively met the needs of the target audience.

3.1 Stakeholders

The first step was to interview one of our stakeholders, the Divisão da Conservação da Natureza e Alterações Climáticas of Funchal. The goal was to find out what was expected, from the characteristics of the game to the context in which it would be used and the topics addressed. The stakeholder expressed a need for a game that could effectively convey information to children about the intricacies of climate change, emphasizing the importance of sustainable practices. Their emphasis was on children, acknowledging them as agents for raising awareness within their families at home. For example, they want children to understand the impacts that are already taking effect and the change in behaviour that needs to occur. Furthermore, the stakeholder was keen on providing insights into actionable steps and choices that children could make to contribute positively to environmental sustainability.

We received a list of existing initiatives in Funchal, organized by our stakeholder, covering many topics:

- **Water**: Water-saving tips; visits to the wastewater treatment plant; games designed to promote awareness of sustainable behaviours, particularly the responsible daily use of water, for children aged 6-7 years old; etc.
- **Climate change**: Dr.Why[4] games.

[4] `https://www.drwhy.pt/`

- **Animal welfare**: Awareness sessions on the duties an owner has to a pet; visit to the municipal kennel.
- **Energy**: Recreational-pedagogical activities about sustainable energies and tips to avoid energy waste.
- **Green spaces**: Visits to the Parque Ecológico of Funchal; etc.
- **Urban solid waste**: Awareness sessions and educational activities on waste management; etc.
- **Competitions/Challenges**: Reusing materials for Christmas; drawing your environment; cleaning Funchal from the sea to the mountains[5]; etc.

From this list, we selected the key sustainability topics to focus on in our game: water management, electricity from renewable energy sources and recycling.

3.2 Initial Game Concept

The game was specifically developed to be played between adults and children, recognizing the value of collaboration and interaction between generations. Engaging adults and children in the same gameplay experience fosters communication, enhances shared learning and promotes discussion on sustainability. Initially designed to feature 11 different mini-games, each corresponding to one of the municipalities of Madeira Island, the games were categorized in the three primary topics: water management, sustainable energy and recycling. The goal was to have players go around the island and help in these different areas. A low-fidelity prototype of the map, illustrating this initial concept can be seen in Fig.1.

However, the feasibility of implementing 11 well designed mini-games came into question. Developing such a wide range of mini-games posed several challenges:

- **Resource Limitation**: To design, program and test 11 individual mini-games required a significant amount of time. Ensuring consistent quality across all of the mini-games would have been a resource-intensive task that exceeded the scope of the project.
- **Balancing Design Quality**: With a larger number of mini-games, there was a chance that these might lack depth and refinement due to the need to distribute resources and attention across multiple gameplay experiences and mechanics. This could have negatively impacted the

[5] `https://pem.funchal.pt/clean-up-the-world-limpar-o-funchal-do-mar-a-serra-2023/`

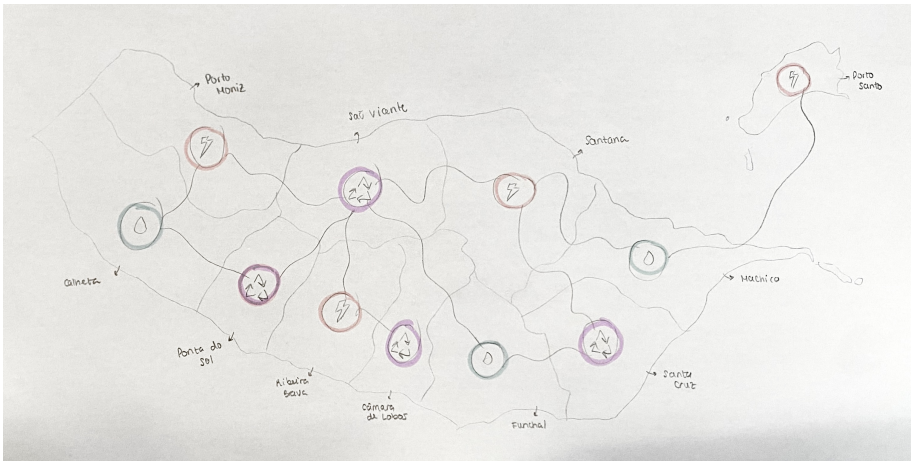


Figure. 1: Low-fidelity Prototype for Game Map Layout

overall user experience and hindered the goal of the game: harnessing ACI to bring awareness to climate change and sustainability.

- **Cohesion and Player Engagement**: Having multiple mini-games could have led to a fragmented gameplay, where each mini-game felt disconnected from the overall goal.

- **Learning Curve**: Introducing players to 11 mini-games, with different game mechanics could result in a cognitive overload, taking away from the overall enjoyment and learning aspect of the game. Reducing the number of mini-games allowed for a more focused and accessible gameplay experience.

- **Project Timeline**: The time required to actually implement and test 11 mini-games would have significantly extended the project timeline, potentially delaying the whole project.

To address these challenges and create a more cohesive and player engaging experience, the number of mini-games was gradually reduced. The initial 11 mini-games were reduced to 6 and eventually to 3. Rather than focusing on quick, stand-alone mini-games, we prioritized a smaller number of richer, more interactive experiences that fostered greater communication and collaboration between players. We believe that by streamlining the number of mini-games, the overall game became more coherent and with and improved gameplay experience.

The transition from the initial concept to the final was iterative, reflecting the adopted methodology. The evolution of the number of mini-games is illustrated through Fig.2, which showcases the high fidelity concept prototypes. The nodes for the mini-games are represented with different

icons, including blue water drops for the water management mini-games, green recycling symbols for the recycling mini-games and the yellow lightning bolts for the sustainable energy mini-games.

(a) 11 mini-games **(b)** 6 mini-games

Figure. 2: High-fidelity Concept Prototypes for Game Map Layout

3.2.1 Personas

To enhance our design process, we have created personas, see Fig.3. From understanding a child's preferences to navigating the intricacies of family dynamics, these personas direct us towards user satisfaction. The deliberate creation of these personas ensures we stay firmly rooted in the user's needs, acknowledging their pivotal role in determining the success of our project. Two adult personas have been included because the game could be played at home or in a classroom.

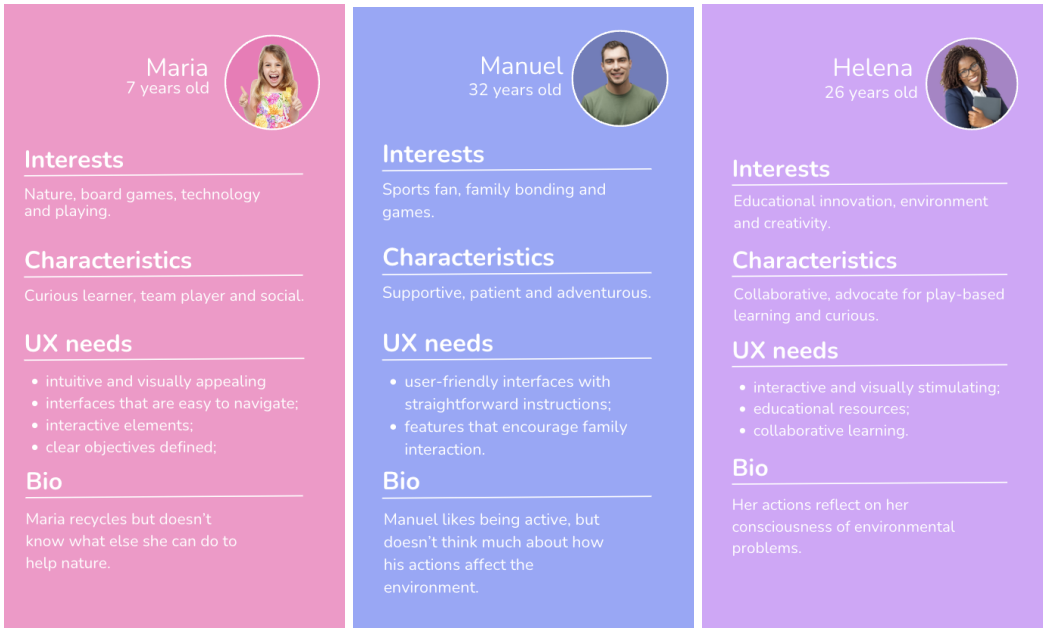


Figure. 3: Persona Cards

In Mystiria, each of the three mini-games is represented by a unique character: Aqua embodies water management; Electro represents renewable energy; and Verdis symbolizes recycling.

3.2.2 Aqua's Mini-Games

For the first iteration of Aqua's mini-games, there were three different mechanics designed, as seen in Fig.4. The first mini-game was the water pipe puzzle, which ultimately became the core

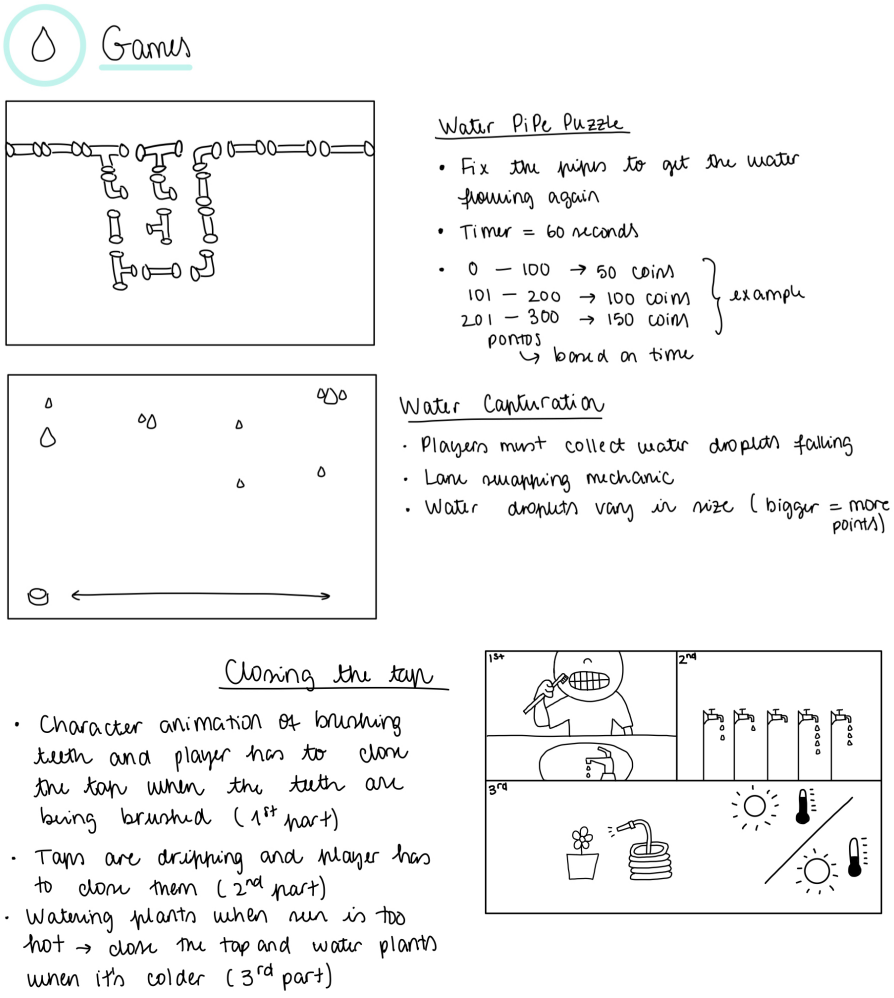
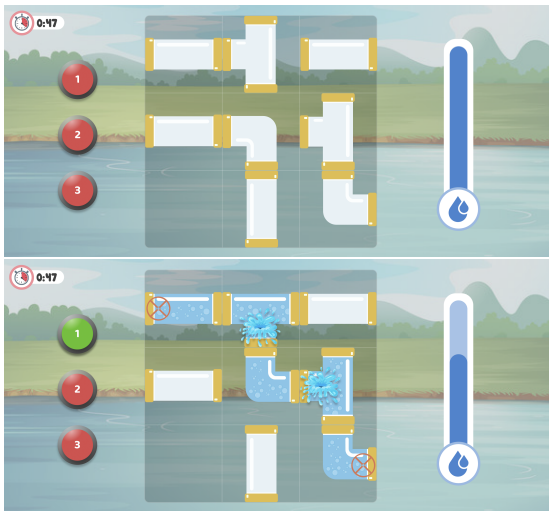


Figure. 4: Low-fidelity Prototypes of Aqua's Mini-game

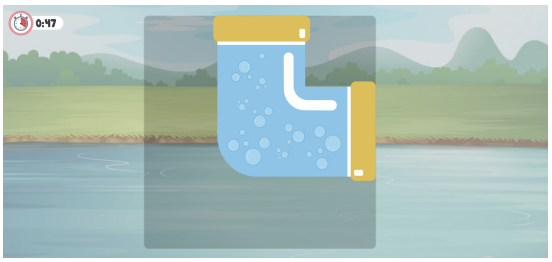
mechanic of the final Aqua mini-game. The second mini-game focused on water capture, where players had to collect water droplets falling from the sky. The larger water droplets were worth more points, encouraging players to strategize their choices carefully. The third and final mini-game was segmented into three different parts. In the first stage, players closed a running tap while an

animated character brushed its teeth, emphasising the importance of turning off taps when not in use. In the second stage, players addressed dripping taps by shutting them off. The final stage challenged players to select the best time to water plants, underlining the fact that watering during the hottest hours of the day will lead to water loss due to evaporation.

After exploring the multiple options for Aqua's mini-game, we concluded that the most promising concept was the water pipe puzzle mini-game expanded with additional levels. The high-fidelity prototype is shown in Fig.5. For the adult screen, the numbers on the left-hand side were intended to indicate the specific puzzle level the players were working on. Meanwhile, the water meter bar was designed to track the amount of water lost over time, with players losing more water the longer they took to complete the puzzle. While these images closely resemble the final design implemented for Aqua's mini-game, several adjudgements were made.



(a) Adult's Screen



(b) Child's Screen

Figure. 5: High-fidelity Prototype of Aqua's Initial Mini-games Concepts

3.2.3 Electro's Mini-Games

In the first iteration of Electro's mini-games, four different concepts were developed and are presented in Fig.6. The first mini-game featured a mechanic similar to Aqua's puzzle game, but adapted to involve connecting wires instead of water pipes. The second mini-game drew inspiration on the mechanic from the popular VR game *Beat Saber*[6], were players swiped at various renewable energy

[6] `https://beatsaber.com/`

sources to collect them. The third game mechanic was a memory card challenge, requiring players to match the cards with the same renewable energy symbols. The last mini-game mimicked one of Aqua's initial game concepts, tasking players with collecting falling energies. This fourth mechanic was ultimately chosen as the core for phase one of Electro's mini-game.

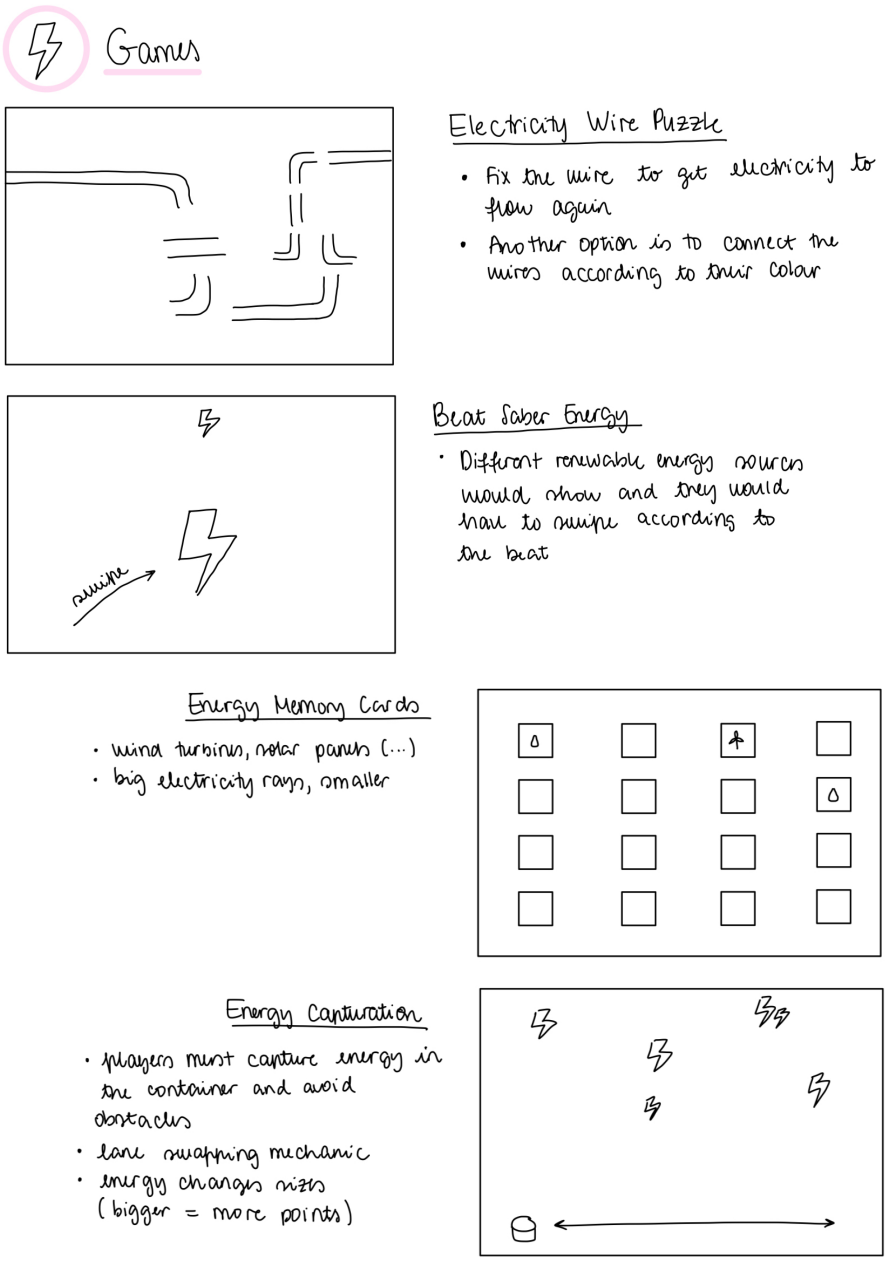
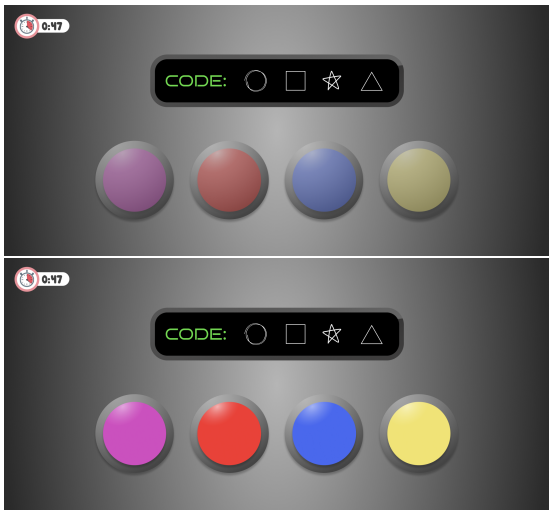


Figure. 6: Low-fidelity Prototypes of Electro's Initial Mini-games

Before this final decision, another iteration with high-fidelity prototypes was completed, in which a completely different mechanic was tested. This mechanic, as illustrated in Fig.9, was

puzzle based. The child had to correctly connect the cables based on the colours and then inform the adult which colour belonged to each of the symbols. The adult then had to press the buttons in the order of the code. For the shown example, the adult would have to press the buttons in the following order - blue, red, pink and yellow. The adult would only be able to press the buttons once the child connected the specific colour for it.



(a) Adult's Screen

(b) Child's Screen

Figure. 7: High-fidelity Concept Prototypes of Electro's Mini-games Concepts

3.2.4 Verdis' Mini-Games

Regarding Verdis' mini-games, four mini-games were initially designed and are portrayed in Fig.8. The first mini-game involved a mechanic that has already been seen on the other characters' mini-games, which is the one based on the *Beat Saber* game. The goal is to swipe the trash away. The second mini-game is a sorting waste challenge in which players must sort the falling trash into the correct recycling bins. The goal of the third mini-game is to move between lanes in order to collect trash. The final mini-game conceptualised for Verdis uses the game mechanic of the memory cards previously discussed.

During the early stages of development, alongside the design of the initial 11 mini-games, we conducted a study to evaluate an existing app called WasteRush[7], developed by WalkMe Mobile Solutions. This app featured a mechanic where players controlled a recycling truck that moved from side-to-side to collect trash while avoiding different obstacles. This study was conducted with

[7] `https://play.google.com/store/apps/details?id=pt.walkme.wasterush&hl=pt`

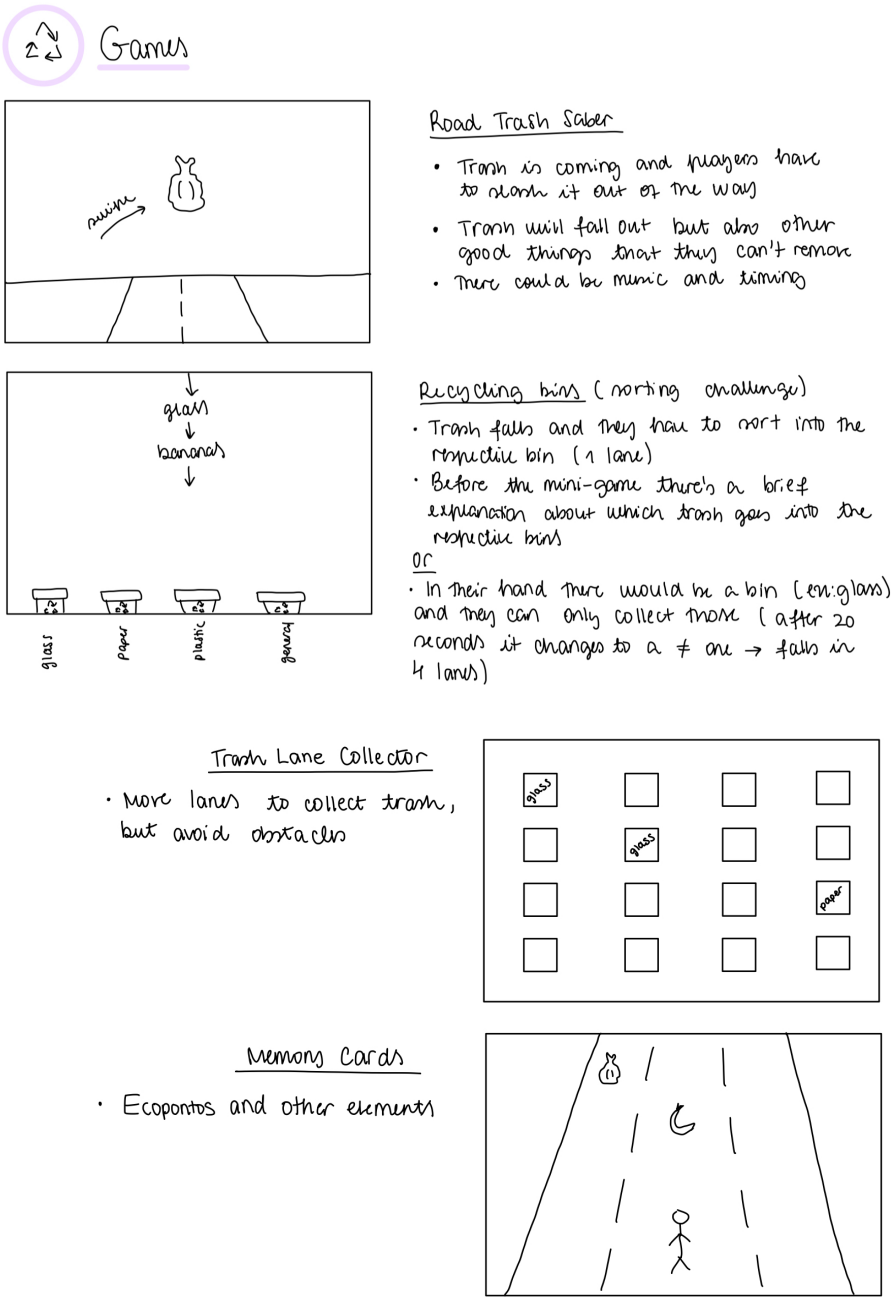
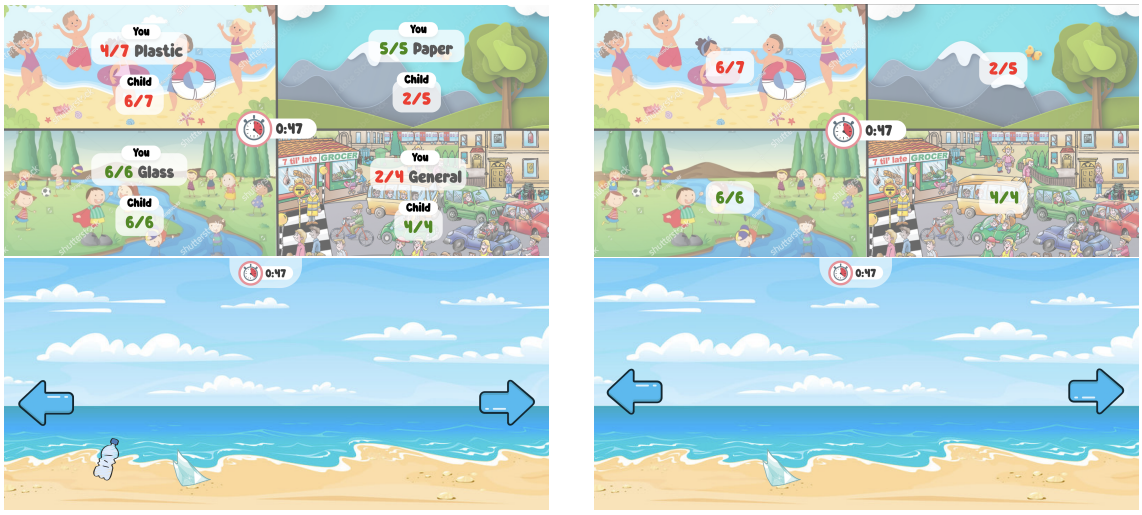


Figure. 8: Low-fidelity Prototypes of Verdis' Initial Mini-games



(a) Adult's Screen **(b)** Child's Screen

Figure. 9: High-fidelity Concept Prototypes of Verdis' Mini-games Concepts

20 participants and involved different tasks (finishing levels 1–6, identifying collectables, coins, and game mechanics), and filling out pre and post-game questionnaires to assess changes in attitudes and understanding (with the NEP [85] scale and additional statements).

The purpose of this study was to analyse the game mechanics and whether the players were able to learn anything new with the provided information.

While the evaluation of the game did not provide a significant role in shaping the overall direction of the mini-games, it provided an idea for the mechanic in Verdis' mini-game. The intuitive nature of the recycling truck's movement in WasteRush demonstrated how simple mechanics can also be engaging and theme appropriate. Inspired by this, the mini-game was designed in which players used a similar side-to-side movement mechanic to collect the falling trash into the recycling bin.

3.3 Experimenting with Technologies

The game was initially designed to feature virtual reality (VR) and augmented reality (AR), as illustrated in Fig.10, that would provide possibilities for improving interactivity and immersion.

This concept involved a hybrid approach where players would interact with a physical board game using a mobile phone, which served as the AR device. The mobile phone would then connect to the VR headset allowing players to seamlessly transition into the immersive mini-games that

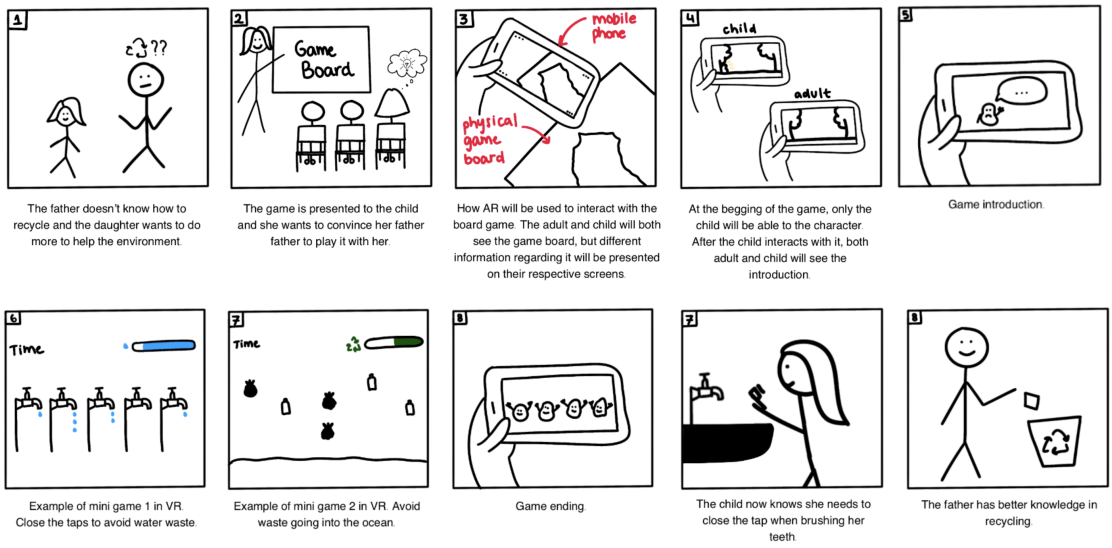


Figure. 10: Initial Game Concept Storyboard

complemented the physical board game experience. This design aimed to blend tangible game objects and digital play, offering an engaging way to address the educational goals of the game.

To explore the feasibility of this concept, we investigated games that effectively integrated these technologies to assess their contributions to the intended gameplay experience. This included analysing how VR could offer players an engaging sense of presence in the simulated environment and how AR could bridge the digital and physical worlds.

However, several challenges led to the decision to abandon this approach:

1. **Ethical Constraints Regarding VR Use by Children:** VR headsets come with specific age recommendations due to the potential health and safety risks, including eye strain, motion sickness and discomfort from prolonged use. For instance, Meta Quest requires users to be at least 13 years old to create their own accounts. Children aged 10 to 12 may use the device, but only with explicit parental consent and supervision. Since our target group for the children is 6-10 years old, incorporating VR technology raised significant ethical concerns.

   – **Health Risks**: The developing visual and neurological systems of younger children are more susceptible to strain and fatigue caused by the immersive nature of VR.

   – **Content Immersion**: The highly immersive experience of VR could blur the lines between the virtual and real world for younger children, potentially causing confusion or distress.

2. **Technical Challenges in Multiplayer Networking**: Integrating multiplayer functionalities with AR and VR posed a significant technical challenge. The original game concept required seamless communication between:
   - A mobile phone (used for AR interactions).
   - A VR headset (used for the mini-games).

   While solutions like the Photon PUN, at first, seemed like a good option, it then proved difficult, especially regarding our time frame for developing the game. Communication between both devices was successfully established, however, the VR experience presented a significant issue: the games appeared in a windowed mode rather than full-screen. This issue meant that the required immersion was not achieved. Despite our efforts to implement a solution, we were unable to solve the problem. This limitation also influenced our decision to ultimately move away from VR integration.
3. **Practical Considerations for AR and VR Implementation**: When developing with AR and VR components it requires substantial hardware, software and testing resources. Ensuring compatibility across devices and delivering a consistent experience for both adult and child players would have extended the development timelines significantly.

Given these limitations, we decided to re-think the game concept and exclude VR and AR elements. Instead, the game was redeveloped with a focus on desktop-based gameplay that maintains its collaborative and educational goals. This decision not only ensures we adhere to the initial timeline, but also increased accessibility and safety of our target audience.

Although we managed to successfully establish a connection between a VR headset, in this case Meta Quest 3[8], and a laptop - which later would have AR integrations - several technical and practical constraints ultimately led to the exclusion of VR and AR from the final prototype. A key limitation was in the way the game build behaved different across platforms: while it ran in fullscreen mode on the PC, the VR headset only displayed the application in a windowed format, significantly diminishing the sense of immersion. This inconsistency not only disrupted user engagement but also interfered with the game dynamics. Additionally, maintaining a stable connection between the headset and the laptop proved challenging, especially under the performance demands of real-time multiplayer interactions. Thus, while these technologies were part of the initial scope

[8] `https://www.meta.com/quest/quest-3/`

and part of the investigation, the games that specifically use these technologies do not align anymore with the goals or capabilities of the final version of the game. As such, these games, although of great value to the research phase, will not be further discussed. This shift allowed for a more refined approach to game design, concentrating on features that align directly with the current technological requirements and gameplay objectives. By streamlining the research, we were able to develop a final prototype that provided a cohesive and polished experience to the users. The final game design can be seen in the next chapter (Chapter 4 - *Mystiria*: Game Design).

By adapting the game's scope, we ensured alignment with ethical standards, minimized development risks and maintained the project's core goal of raising awareness about climate change and sustainability through collaborative play.

4 *Mystiria*: Game Design

The final game design of *Mystiria* represents a culmination of the multiple iterations of this project and was carefully designed to attract and engage both adults and children. In this chapter the game design decisions will be discussed, highlighting game mechanics, game structure, narrative and user interaction. This discussion will focus on how the game's structure promotes collaboration between players, each assuming distinct roles during the asymmetric gameplay of the mini-games. Furthermore, this chapter also explores how Mystiria integrates real-world elements with a local context - Madeira Island - to support its educational objectives.

4.1 Game Concept

Mystiria is a collaborative serious game designed to raise awareness about climate change and sustainability. Its main goal is to create an immersive experience in which an adult and a child must work together to solve environmental challenges. The game's concept is structured around four main pillars: adult-child interaction, intergenerational learning, asymmetric play and local context. Fig.11 shows how the game is supposed to be played and highlights what each of the players will be seeing during the mini-games. For a demonstration of the game please refer to the video[9].

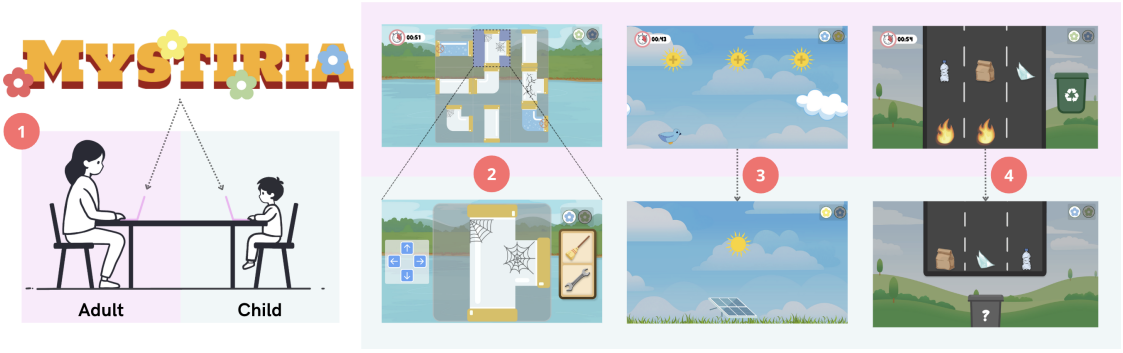


Figure. 11: Collaborative Gameplay Structure of Mystiria: (a) **Adult Child Collaboration** - Each of the players has their own screen, which the other player is not allowed to see. The goal is for both players to communicate with each other; (b) **Aqua's Mini-game** - the adult (top image) sees and solves the whole puzzle, while the child will move around and have to clean/fix the pipes based on adult input; (c) **Electro's Mini-game** - the adult (top) will have to spawn sun rays and avoid enemies, while the child (bottom) tries to catch them with the solar panel; (d) **Verdis' Mini-game** - the adult (top) will have to put out the fires to avoid the trash being burnt while also informing the child (bottom) what the current recycling bin is so that they can catch the correct waste type.

[9] `https://www.youtube.com/watch?v=ttlno9THyRg`

As discussed in Chapter 2 - Literature Review, the game is centred around a local context, specifically Madeira Island. This focus is evident in various aspects of *Mystiria*, notably in its map, which is actually the map of Madeira Island. By incorporating a familiar and local setting, we hope to foster a stronger emotional connection with players, enhancing their sense of empathy and engagement with the content. Additionally, towards the end of the game players will be able to explore renewable energy sources in various locations of Madeira, reinforcing a tangible link between the game's themes and a real-life commitment to sustainability.

4.2 Narrative

The narrative of *Mystiria* plays a crucial role in creating an immersive environment for players, providing a meaningful learning experience. Set in the mystical and once thriving island of Mystiria, the game follows the journey of two travellers - an adult and child duo - who arrive to find the island in distress. Once a paradise where humans lived in harmony with nature, Mystiria was abandoned 50 years ago due to the consequences of climate change, including rising sea levels, extreme temperatures, and unsustainable human practices. Now, guided by the island's heart and spirit Perla, players must restore the balance by solving environmental challenges. Perla will introduce the players to other characters - Aqua, Electro and Verdis - each representing a critical aspect of sustainability. Through teamwork, players learn the importance of sustainable practices and how cooperation across generations may help ensure that Mystiria - and the real world - can heal and restore balance once again.

The guardians of Mystiria that will guide the players through their journey are:

- **Perla (the heart and spirit of Mystiria)**: this character introduces the players to the island and its history. Perla explains what led to the island's decline and encourages players to restore its former beauty.
- **Aqua (the guardian of water)**: Aqua highlights the importance of water conservation and management. In Aqua's mini-game, players must restore the island's water distribution system and ensure clean water access.
- **Electro (the guardian of electricity)**: Electro educates players on the importance of renewable energy sources. In Electro's mini-game, players must collect solar energy to restore electricity in the island and move away from fossil fuel dependency.

– **Verdis (the guardian of recycling)**: Verdis focuses on waste management and the importance of recycling. In the mini-game, players must effectively clean up the island by recycling waste and preventing it from burning, reducing further environmental harm.

By having this narrative structure that draws on themes of environmental stewardship and collective responsibility, emphasises is being made on the long-term consequences that human actions can have on ecosystems. This also mirrors real-world climate change dynamics, in which communities often fail to thrive due to the negative impacts brought on due to climate change [86], including environmental degradation, resource depletion and socioeconomic impacts.

The narrative's backstory of the island's fall due to human action serves as an important lesson for the players, highlighting the need for sustainable practices and environmental responsibility.

Apart from this, the dialogue also emphasises hope and empowerment, by offering players a chance to help heal *Mystiria*. By portraying the players as key figures in reversing the damage, the narrative aligns with theories of environmental psychology, which highlight the importance of empowering individuals in order for them to act for environmental change [87].

(a) Perla **(b)** Aqua **(c)** Electro **(d)** Verdis

Figure. 12: Game Characters

The game characters (see Fig.12) were developed using Midjourney[10] with variations of the following prompts:

– Perla -"a very cute and mystical spirit guide based in the laurissilva forest, pixar animation, full body, 3d, happy and peaceful"

– Aqua - "a cute and mystical spirit guide about hydrological balance, pixar style, full body, 3d, happy and peaceful"

[10] `https://www.midjourney.com/home`

– Electro - "a cute and mystical spirit guide of electricity with bolts, pixar animation, full body, 3d, happy and peaceful"

– Verdis - "a cute and mystical spirit guide which is responsible for all recycling, recycling elements, pixar style, full body, 3d, happy and peaceful, recycling symbol"

4.3 Gameplay

Regarding gameplay, the diagram in Fig.13 illustrates how the game progresses and provides a clear structure of events.

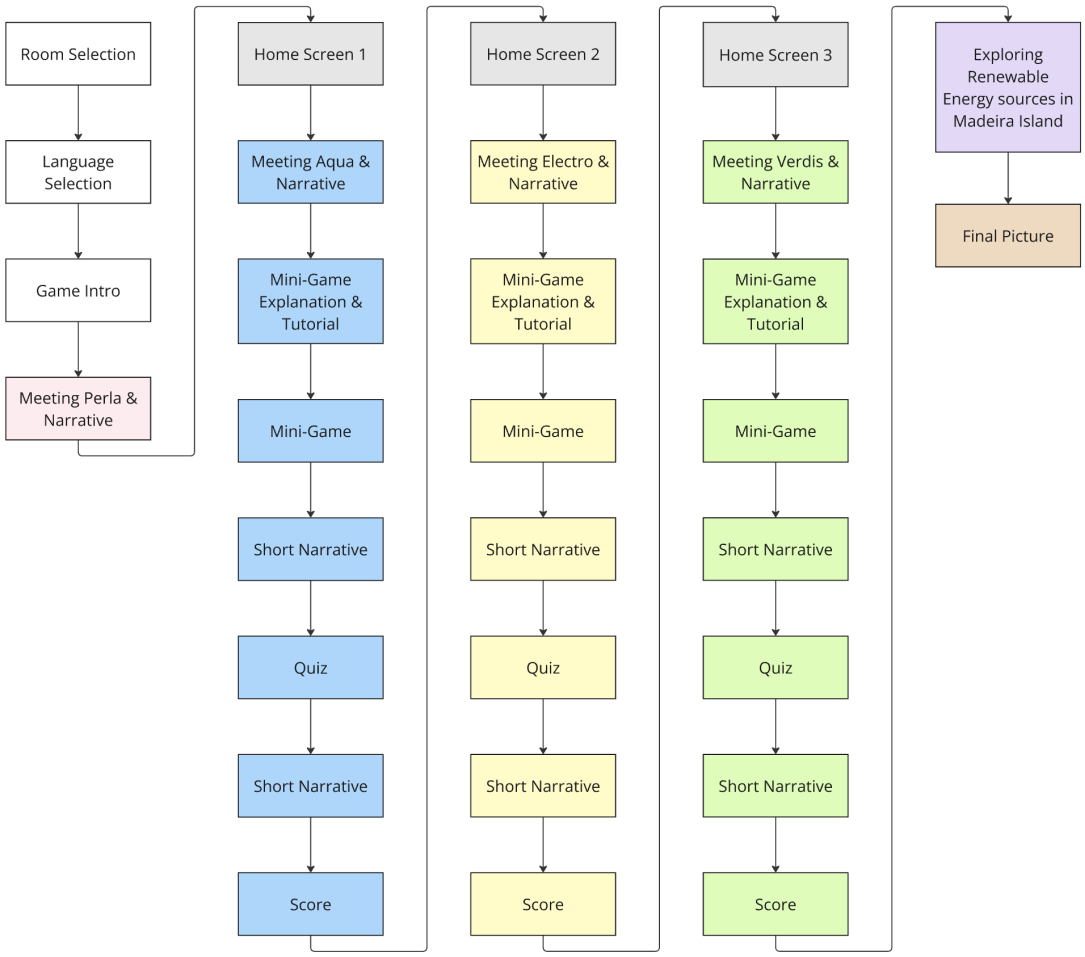


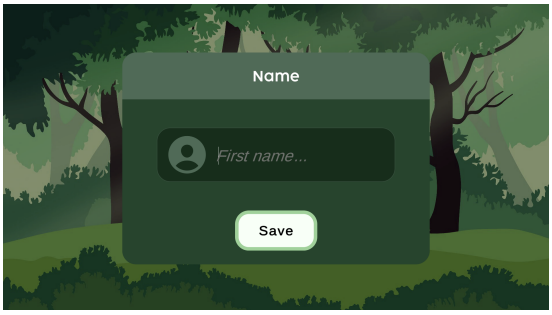
Figure. 13: Flow Diagram of Game Scene Progression

The diagram provides a visual representation of how players will navigate through the different stages of the game. Some components, such as progressing through narrative scenes, tutorials and

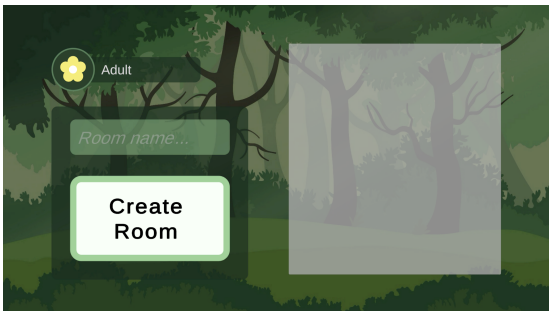
clicking the home button, are exclusively controlled by the adult. This ensures that the child cannot accidentally trigger these actions, preventing players from missing key information about the game.

4.3.1 Initial Gameplay

The initial gameplay involves Room Selection (Fig.14), Language Selection (Fig.46 in Chapter 6 - Implementation) and Game Intro. Upon launching the game, players are prompted to enter their name, see Fig.14a. Each player is assigned a flower icon, displayed in the top left corner of Fig.14b, the purpose of which will be explained later in this section.



(a) UI Layout for Players to Insert their Name

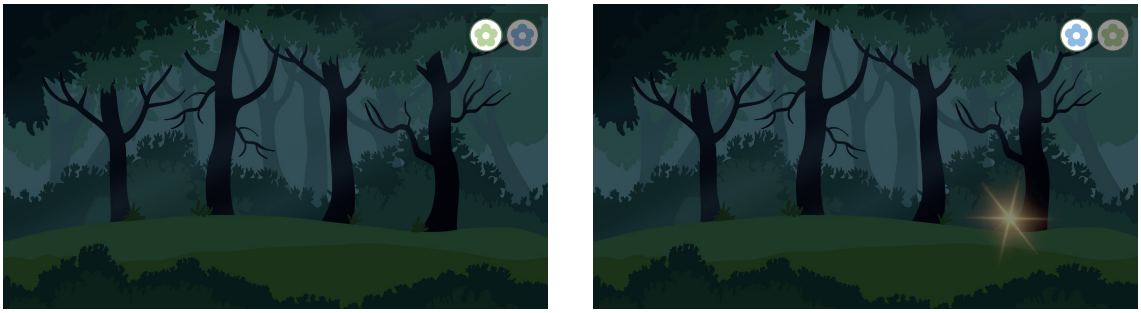


(b) UI for the Room List (on the right) and the Creation of a New Room

(c) UI Layout for the Adult Player, as they can Start the Game

Figure. 14: Different Scenes for the Room Selection

As the game begins, after the adult presses start, the adult and child are both seeing a dark forest, but the child is able to see an additional element - a slowly flashing light illustrated in Fig. 15b. The child triggers an animation by pressing this element, that takes players to meet the first character, Perla. The icons on the top right serve the purpose of informing players if they are seeing the same scene as one another. If the icon on the right appears gray, it indicates that the other player is viewing a different screen from the current player.



(a) Adult's Screen **(b)** Child's Screen with the Flashing Object

Figure. 15: Introduction Scene Before Meeting Perla

Onto Meeting Perla & Narrative (refer to Fig.16), this character introduces the narrative previously mentioned. Perla's acknowledgement that the island's decline was a result of neglecting nature's balance reinforces the idea that environmental degradation is not an isolated incident but a collective, often unconscious, outcome of human behaviour [88]. Perla then calls upon the players to embark on a collaborative mission to restore harmony to the island by interacting with other pivotal characters and discovering how they can contribute to the solution.

Figure. 16: UI Layout for All of Perla's Narrative Scenes

After Perla, players will see for the first time the map of Mystiria (Fig.17a). This is Home Screen 1 and as illustrated by the icon in the map, players will meet Aqua next. Home Screen 2 and Home Screen 3 are represented in Fig.17b and Fig.17c respectively. Each home screen represents the starting points for meeting a new character and engaging in the associated narrative, mini-game and quiz.

The mini-games in *Mystiria* are integral to both the gameplay experience and the educational objectives of the study. Each mini-game has been designed to immerse players in a specific environmental challenge, encouraging collaboration, communication and critical thinking while promoting awareness about climate change and sustainability. Through these interactive experiences, players

(a) Home Screen 1 - Beginning of Aqua's Mini-Game highlighted by the Icon Present in the Map Being a Water Droplet

(b) Home Screen 2 - Beginning of Electro's Mini-Game as the Icon Available to Press is Electricity

(c) Home Screen 3 - Beginning of Verdis' Mini-Game as the Icon Available to Press is Recycling

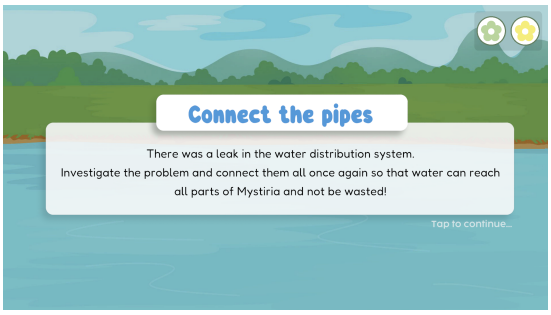
Figure. 17: *Mystiria's* Map with the Progression for the Different Home Screens

are encouraged to understand the underlying issues, and reflect on their impact on the environment. A more detailed explanation of the logic behind the game mechanics of each level is available in Chapter 5 - System Design and Architecture.

4.3.2 Aqua Mini-Game - Connect the Pipes

To start, players will meet Aqua, see Fig.18, at which point the character will introduce itself and the water management topic. Before the mini-game, players will see an explanation and tutorial, depicted in Fig.19.

Figure. 18: UI Layout for All of Perla's Narrative Scenes



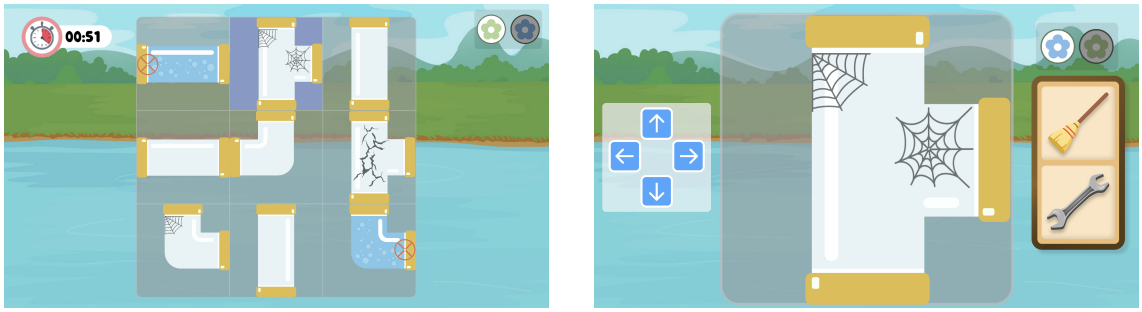
(a) Mini-Game Explanation

(b) Mini-Game Tutorial

Figure. 19: Aqua's Mini-Game Introduction

This will be the first mini-game that players will get a chance to interact with. It is related to water management and highlights the importance of maintaining an efficient and clean water distribution system. The mini-game is split into three different phases, each will increase progressively in difficulty and complexity, requiring better communication between the adult and child playing. In the first phase, players have 60 seconds to complete the puzzle, followed by 90 seconds for the second phase and 120 seconds in the final phase. The remaining time is displayed to the adult in the top left corner, and when only 10 seconds remain, a sound effect will play as a warning.

In the first phase, the water distribution system is represented by a 3x3 grid of pipes. The adult player is given the task of solving the puzzle by arranging the pieces so that the necessary pipes of the water system are connected properly, enabling water to flow from one pipe to another. The adult can see the whole grid at once, see Fig. 20a, and must strategically rotate each pipe to create a continuous path. Meanwhile, the child takes on the role of the cleaner/repairer. The child's goal is to move around the puzzle using the provided arrows and clean the spider webs using a broom and/or fixing the leaks in the pipes with the wrench, ensuring water is able to flow smoothly. However, the child can only see one of the pipes at a time, see Fig. 20b, making it mandatory to communicate with the adult for guidance. The adult can track the child's current pipe location by the position of the blue box. However there is a caveat, even if the child removes all of the spider webs and fixes the leaks, they will reappear if the adult does not solve the puzzle first. For the water to flow, the pipes need to be in their correct positions and those pipes also have to be clean and have no leaks. This collaboration not only stimulates real-world challenges in water management but also emphasizes the value of effective communication and teamwork.



(a) Adult's Screen **(b)** Child's Screen

Figure. 20: Aqua's Mini-game - Phase One

For the second phase, the complexity increases with the introduction of a 4x3 grid, as seen in Fig. 21. This new layout expands the puzzle, requiring the adult to work with a larger, more intricate arrangement of pipes. As the puzzle grows in size, the adult is faced with a greater challenge as he needs to determine how best to connect the pipes, while also instructing on where the child should go. With the larger grid, the child has more sections to attend to, so the adult must be more specific with their instructions. At this stage, the collaboration increases, hence both players will need to manage their tasks more efficiently without wasting much time.

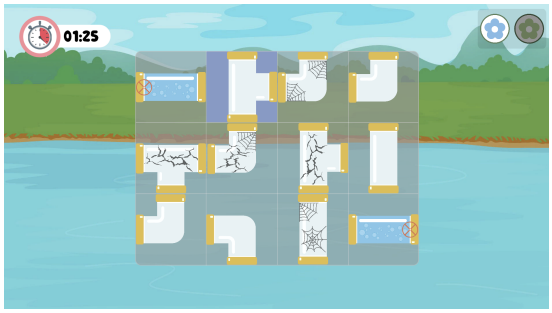


Figure. 21: Aqua's Mini-game - Phase Two

The final phase, consists of a 4x4 grid, presented in Fig. 22. The tasks remain the same, but as the complexity increases, players will have to keep communicating, to ensure the puzzle is solved and water can flow freely, in the shorter time possible.

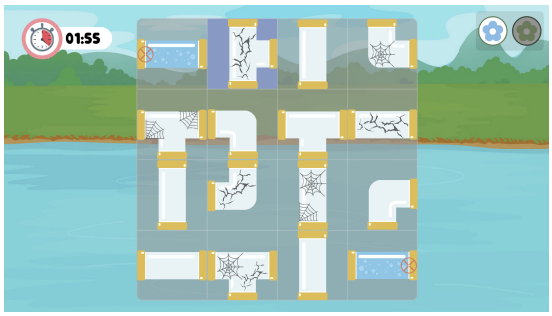


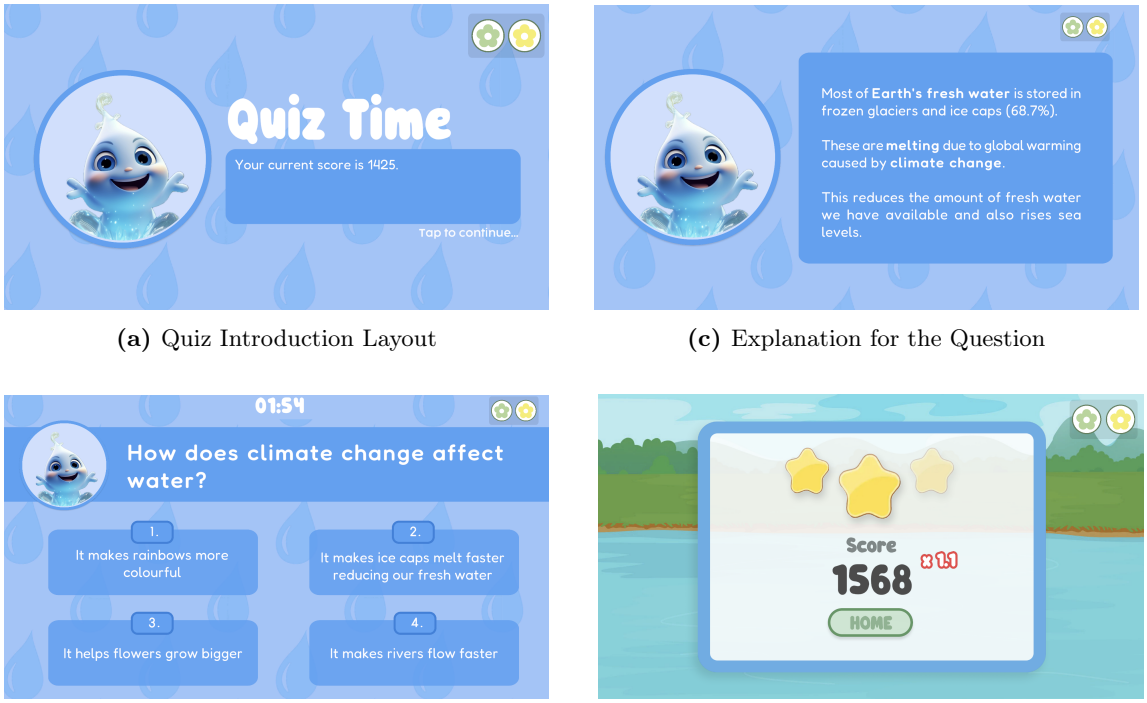
Figure. 22: Aqua's Mini-game - Phase Three

The three phases of this mini-game provide a progressively challenging experience that reinforces the importance of teamwork, problem-solving, and effective communication. By working together to restore the water distribution system, players learn about the complexities of water management, and the consequences of mismanagement, while also engaging in a fun and educational experience. This mini-game not only teaches players about the importance of water conservation but also models how collaboration can lead to more effective environmental solutions. Through each increasing level of difficulty, the game fosters an understanding of how seemingly small actions, like repairing a pipe or cleaning a section of the system, are vital in maintaining a sustainable water infrastructure.

The score for Aqua's mini-game is based on how quickly players complete the phases. The faster they finish, the higher the score will be. The time taken to solve each of the phases is then divided by the maximum time for each and then multiplied by 1000.

After the mini-game, players will take part in a quiz, related to the character's topic (Fig.23). With every question they get right, they will increase their previous score:

- **1 question answered correctly**: The score will be multiplied by 1.1;
- **2 questions answered correctly**: The score will be multiplied by 1.2;
- **all questions answered correctly**: The score will be multiplied by 1.3.



(a) Quiz Introduction Layout

(c) Explanation for the Question

(b) Question

(d) Score

Figure. 23: Aqua's Quiz Scenes and Score

The questions and answers of the questionnaire can be seen in the section of the Quiz, further along the text.

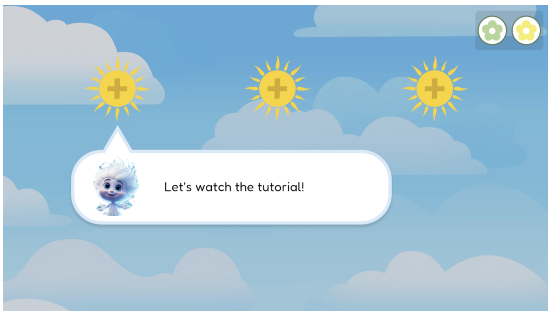
This final score is then presented to players, see Fig.23d, both written and using stars. Players will get one star if the score is below 1500, 2 stars if the score is between 1501 and 2999, and 3 stars if the score is above 3000. This star system logic is applied to all of the mini-games.

4.3.3 Electro Mini-Game - Sunshine Savers

Players first meet Electro (see Fig.24), who introduces itself and the topic of renewable energy sources. Then, before the mini-game, players are presented with an explanation and tutorial, as shown in Fig.25.

Figure. 24: UI Layout for All of Electro's Narrative Scenes

(a) Mini-Game Explanation



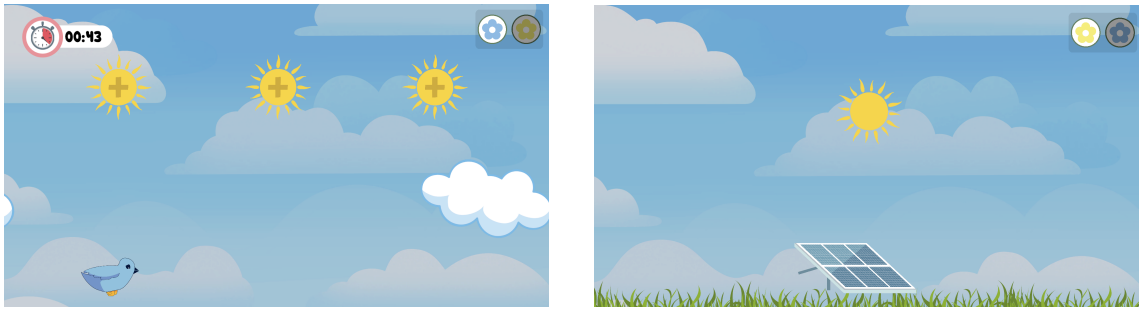
(b) Mini-Game Tutorial

Figure. 25: Electro's Mini-Game Introduction

The second mini-game in *Mystiria*, Sunshine Savers, keeps pulling on the collaborative side as players need one another to be able to get points. This mini-game shifts the players' attention from water management to renewable energy sources, in particular, solar energy.

This mini-game is divided into two interconnected phases. For both phases players will have 60 seconds to complete them. In the first phase, the adult has to spawn suns (see Fig. 27a) for the child to catch using the solar panel (see Fig. 27b), however, the adult's task is complicated by the presence of enemies that move across the screen at different intervals. The cloud enemy moves across the screen from right to left at a constant spawn interval of 7 seconds, while the bird moves from left to right with varying spawn interval (between 7 and 15 seconds). If one of the spawned suns touches an enemy, it will disappear, resulting in a loss of possible points. So, the adult must strategically time and position the suns to avoid these obstacles. Simultaneously, the child is responsible for manoeuvring the solar panel to catch as many of the falling suns as possible, maximizing the players' score. For every sun the child catches, 150 points are added to the score.

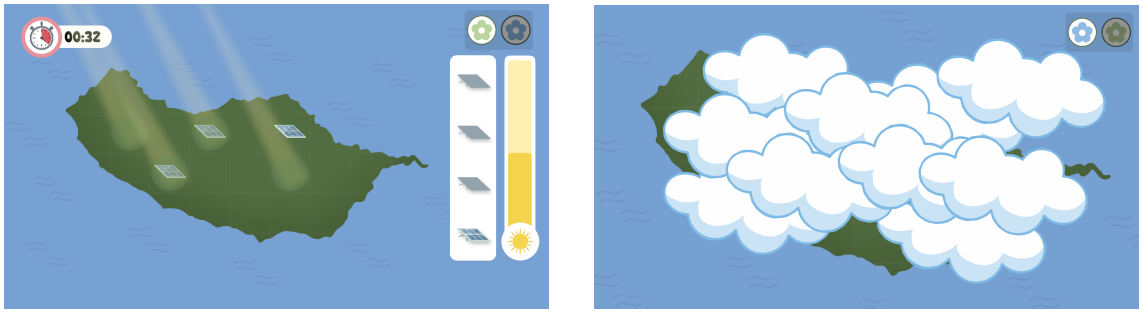
In the second phase, players collaborate to strategically place solar panels throughout *Mystiria*, aiming to maximize sunlight exposure and improve energy efficiency. The adult player is responsible for placing solar panels in the illuminated areas to fill the light meter, as shown in Fig. 27a, while



(a) Adult's Screen **(b)** Child's Screen

Figure. 26: Electro's Mini-game - Phase One

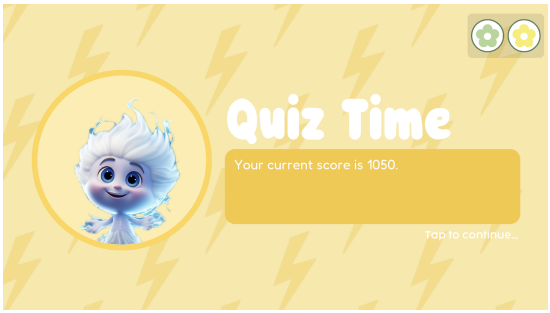
the child must clear clouds obstructing sunlight on their screen, depicted in Fig. 27b. The island features a dynamic grid system where focal points of sunlight change location every couple of seconds. The intensity of these focal points is correlated to the number of clouds present on the child's screen, reinforcing the need for cooperation between both players. The mechanic present in this mini game are designed to foster continuous engagement and dynamic collaboration, requiring constant communication and teamwork between both players to succeed. Half of the score from the first phase is multiplied by the average of how many solar panels were in the correct place. The remaining half remains unchanged to ensure that players to not lose all their points if they performed poorly in the second phase.



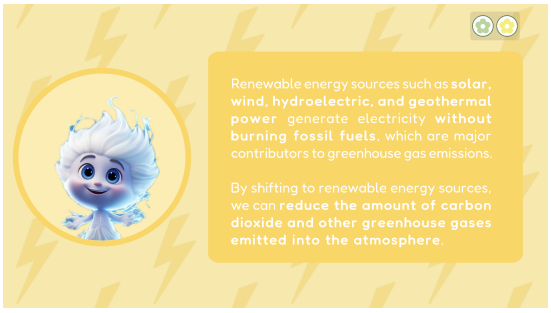
(a) Adult's Screen **(b)** Child's Screen

Figure. 27: Electro's Mini-game - Phase Two

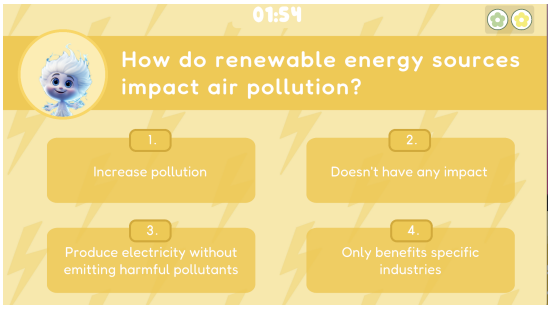
After the mini-game, players will take part in a quiz, related to the character's topic (Fig.28).



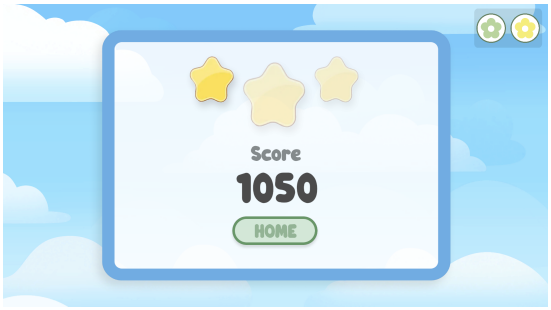
(a) Quiz Introduction Layout



(c) Explanation for the Question



(b) Question



(d) Score

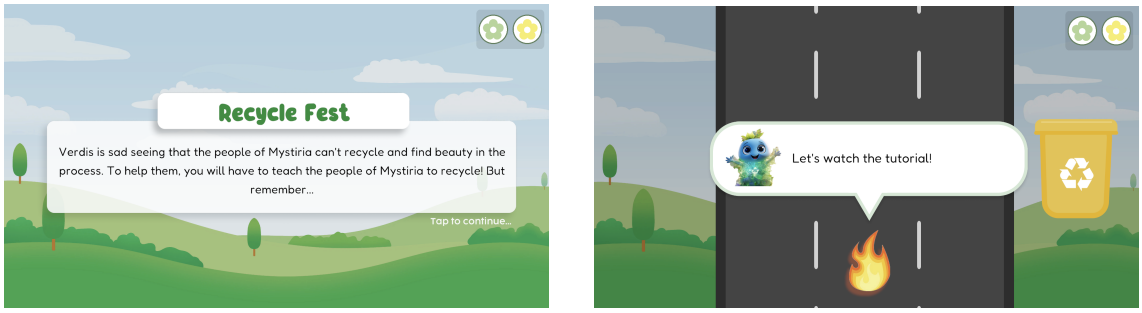
Figure. 28: Electro's Quiz Scenes and Score

4.3.4 Verdis Mini-Game - Recycling Fest

Players meet Verdis (see Fig.29), who introduces itself and the topic of recycling. Before the mini-game, players are presented with an explanation and tutorial, depicted in Fig.30.

Figure. 29: UI Layout for All of Verdis' Narrative Scenes

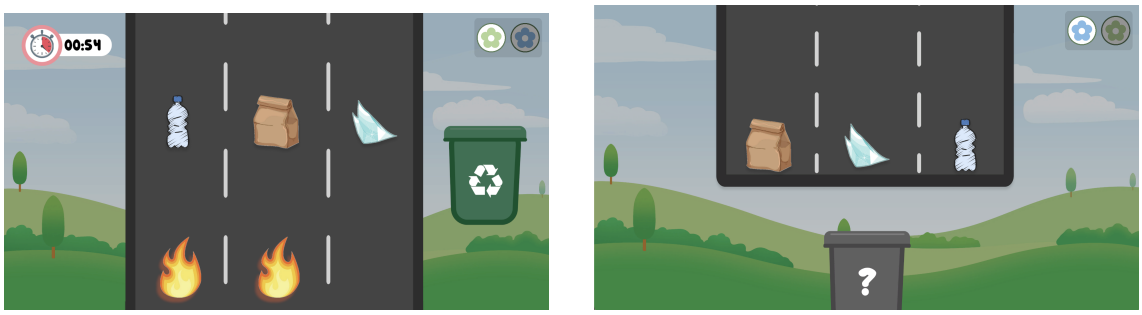
The final mini-game focuses on teaching players about proper waste sorting, and players have 60 seconds of gameplay. This activity requires both the adult and the child to collaborate in placing the trash in the correct recycling bin, whilst also managing environmental hazards.



(a) Mini-Game Explanation **(b)** Mini-Game Tutorial

Figure. 30: Verdis' Mini-Game Introduction

In this mini-game, the adult has two main responsibilities: first, informing the child what the current recycling bin is so that the child can recycle the correct trash in the according bin; and second, extinguish the fires that sporadically spawn on screen, to prevent trash from being burnt and possible points lost (see Fig.31a).



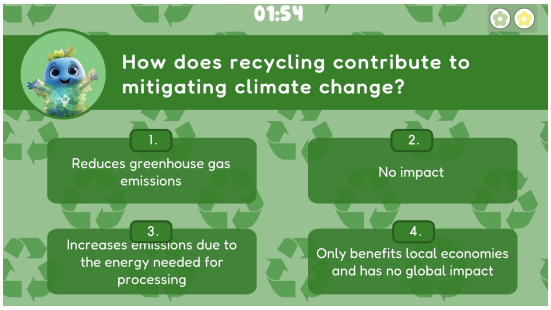
(a) Adult's Screen **(b)** Child's Screen

Figure. 31: Verdis' Mini-game

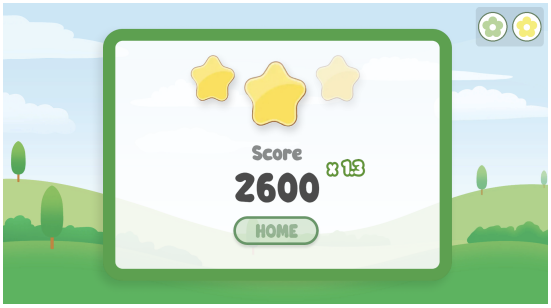
The need for the adult to inform the child the current recycling bin, increases the collaboration aspect, and ensures that both parties have to be alert and communicating to achieve the highest score possible. The knowledge transfer we are hoping to achieve by burning the trash is to highlight the negative consequences of improper waste management, such as pollution and loss of recyclable materials. This mechanic serves as a tangible demonstration of the importance of sorting and recycling trash correctly, reinforcing the educational goal of raising awareness about sustainable waste disposal practices and their impact on the environment. Meanwhile, the child's role is to catch the falling trash in the correct recycling bin (illustrated in Fig.31b), that will be indicated by the adult. For every correctly sorted trash, 200 points are added to the score, but for every trash that gets burnt, 100 points are deducted.

(a) Quiz Introduction Layout

(c) Explanation for the Question



(b) Question



(d) Score

Figure. 32: Verdis' Quiz Scenes and Score

After the mini-game, players will take part in a quiz, related to the character's topic (Fig.32).

4.3.5 Quiz

We have decided that incorrect answers will not impact the players' score negatively, as our goal is to encourage learning and ensure players feel free to explore without the fear of losing points.

The questions in the game were inspired by global and widely accepted resources that address climate change, renewable energy, and sustainable practices. These include publications by inter-governmental organizations like the United Nations Framework Convention on Climate Change (UNFCCC), the Intergovernmental Panel on Climate Change (IPCC), and others. For each of the questions asked, the focus was that they had to relate to the current character's main message and had to align with the latest findings on climate change, the impacts it has, and actionable solutions for individuals. The goal was to create educational content that is scientifically accurate. Appendix B presents the questions, respective options and correct answers used in the final game prototype.

4.3.6 Final Gameplay

Towards the end of the game, players will get to explore various renewable energy initiatives across Madeira Island, allowing them to discover real-world efforts being made locally. The initiatives chosen to take part in this project are:

– **Solar Energy**:

- Photovoltaic Park in Caniçal, built in 2010 and has around 28.800 solar panels [89].
- Photovoltaic Park in Paúl Serra that has around 32.000 solar panels [90].

– **Wind Energy**:

- Eolic Park in Caniçal.
- Eolic Park in Paúl da Serra - Parque Eólico do Loiral III.

– **Hydroelectric energy**:

- Storage Dam in Pico da Urze, Paúl da Serra.

For each of these initiatives, players will be able to see their general location on the map accompanied by photographs (Fig.33). All photographs were taken by the author, except for the satellite images, which were sourced from Google Maps[11]. These initiatives are having an incredible impact on Madeira Island, and as of recent data, renewable energies account for about 33% of the island's energy [91]. Porto Santo Island is also part of the renewable energy wave, and as of 2022, 15,2% of the island's consumption [92] relied on renewable energy sources. There have been recent improvements and future plans that only come to show how Madeira and Porto Santo are committed to advancing renewable energy integration and achieving greater energy independence.

As a final highlight, players will commemorate their journey with a group photo alongside all the characters they have encountered throughout the game (Fig.34). This final keepsake serves as a reminder of the adventure they shared and the important lessons learned about sustainability and climate change. By capturing this moment, the game highlights that collective efforts can make a meaningful difference, encouraging players to carry on the knowledge they have gained and apply it in real life.

[11] `https://www.google.pt/maps`

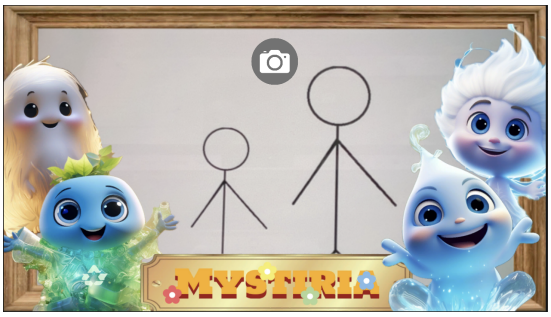
(a) Perla Explaining to Players

(b) Map with Different Renewable Sources to be Seen

(c) An Example of the Multiple Pictures Available

Figure. 33: Renewable Energy Sources in Madeira Island

(a) Introduction by Perla



(b) Picture Frame with Characters

Figure. 34: Picture with Characters

5 System Design and Architecture

In this chapter, the elements required for the development of the final prototype game are presented. These include the system requirements, quality attributes, use cases, UML diagrams and the system architecture.

5.1 System Requirements

System requirements are essential for the development of any system, as they define the needs the system must meet to ensure proper operation, usability and user satisfaction. These requirements act as a blueprint that outlines what the system should do and how it should perform.

Functional requirements describe the specific behaviours and functionalities the game should support, while non-functional requirements define how the system should work to ensure reliability, performance and user experience.

5.1.1 Functional Requirements

Next, a list of the functional requirements for this project will be presented. Each requirement will be identified with the prefix "FR" (Functional Requirement), followed by the initials that represent the respective functionality.

Gameplay features:

- **FR_GP1**: The system shall support multiplayer functionality to allow the interaction between adult and child.
- **FR_GP2**: The system shall provide distinct gameplay roles for each player during the three different mini-games. These include:
  - **FR_GP2.1**: The system shall allow the adult player to see the remaining time on the timer.
  - **Mini-game 1: Connecting the Pipes - Aqua**
    - **FR_GP2.2**: The system shall allow the adult player to rotate the pipes to solve the puzzle.

    * **FR_GP2.3**: The system shall allow the adult player to know the child player's location.
    * **FR_GP2.4**: The system shall allow the child player to only see one pipe at a time.
    * **FR_GP2.5**: The system shall allow the child player to use the arrows to move to different pipes.
    * **FR_GP2.6**: The system shall allow the child player to use the broom or wrench to clean the spider webs or fix the pipes.
    * **FR_GP2.7**: The system shall re-spawn the spider webs or cracks in the pipes, even if the child player has already cleaned/fixed them, if the adult player still has not found the solution to the current pipe puzzle.
    * **FR_GP2.8**: The system shall show the water flowing once the pipe is in the correct position, the previous pipes are in the correct position and there are no crack/spider webs on the pipe.
    * **FR_GP2.9**: The system shall progressively increase the puzzle difficulty (3x3, 4x3, and 4x4 grids).

- **Mini-game 2: Sunshine Savers Phase 1 - Electro**
    * **FR_GP2.10**: The system shall allow the adult to be able to press on one of the three suns ("parent sun") in order to spawn another sun ("child sun").
    * **FR_GP2.11**: The system shall allow "child sun" to move towards the bottom of the screen.
    * **FR_GP2.12**: The system shall allow the "parent sun" to go into cool down for 1.5 seconds before the adult player can press it again.
    * **FR_GP2.13**: The system shall allow for the "child sun" to be deleted if it touches one of the enemies.
    * **FR_GP2.14**: The system shall allow the child player to move a solar panel interactively to catch the falling suns ("child sun").

- **Mini-game 2: Sunshine Savers Phase 2 - Electro**

    * **FR_GP2.15**: The system shall allow the adult player to place solar panels on the island.
    * **FR_GP2.16**: The system shall have 4 light spots across the island that change position every 4 seconds.
    * **FR_GP2.17**: The system shall have a bar meter that represents how many of the solar panels are placed in the correct place.
    * **FR_GP2.18**: The system shall change the intensity of the light spots based on the amount of clouds on the child player's screen.
  - **Mini-game 3: Recycle Fest - Verdis**
    * **FR_GP2.19**: The system shall allow the adult player to see what the current recycling bin is.
    * **FR_GP2.20**: The system shall allow the child player to sort waste items correctly.
    * **FR_GP2.21**: The system shall spawn fires to consume the trash, which the adult player must remove to not lose points.
- **FR_GP2.22**: The system shall provide interactive feedback for player actions, including visual and auditory cues.
- **FR_GP2.23**: The system shall include a quiz after every mini game.

User interface:

- **FR_UI1**: The system shall provide, during the mini-games, separate user interfaces for the adult and child players.
- **FR_UI2**: The system shall have icons that reflect whether the players are both seeing the same screen or not.

Multiplayer functionality:

- **FR_M1**: The system shall support same network multiplayer.
- **FR_M2**: The system shall allow players to reconnect to an ongoing session within a defined time.

- **FR_M3**: The system shall allow players to define their username.
- **FR_M4**: The system shall allow players to create a room, which will be displayed on room list. The creator of the room becomes the Master Client.
- **FR_M5**: The system shall allow for only the Master Client to start the game.
- **FR_M6**: The system shall remove a room from the room list once the room has 2 players inside.
- **FR_M7**: The system shall remove a room from the room list once the creator of the room leaves (while in lobby).
- **FR_M8**: The system shall only allow the Master Client (adult player) to press the buttons that make the scenes change (Ex: "Home" button, "Tap to continue" in the narrative scenes, etc.

Accessibility:

- **FR_A1**: The system shall support language localization including English and Portuguese.

Data Management:

- **FR_DM1**: The system shall log gameplay data, including:
  - Session ID;
  - Duration of the gameplay;
  - Answers of the questionnaires;
  - Score for each of the mini-games;

5.1.2 Non-Functional Requirements

A list of the non-functional requirements for this project will be presented. Similarly to the functional requirements, each of the non-functional requirements will be identified with the prefix "NFR".

- **NFR1**: The system shall ensure that the initial loading time does not exceed 5 seconds on devices that meet the minimum requirement.

- **NFR2**: Scene transition shall occur within 3 seconds.
- **NFR3**: The system shall support multiple concurrent rooms, each accommodating a maximum of 2 players.
- **NFR4**: The system shall allow players to resume gameplay within 60 seconds after a disconnection.
- **NFR5**: The code shall be commented, organized and easily understandable for easy future maintenance.
- **NFR6**: The system shall enforce a maximum network latency of 100ms.

Quality attributes are also part of non-functional requirements used to evaluate system-wide properties [93]. For our project, these attributes are:

- **Usability**:
  - The system should have an intuitive interface that is easy for both adults and children to use.
  - The system shall provide clear instructions.
- **Engagement**:
  - The system shall provide an immersive and interactive gameplay experience.
  - The collaborative nature of the system shall foster communication and teamwork between players.
- **Performance**:
  - The system shall operate smoothly and have a high performance.
- **Scalability**:
  - The system shall allow developers to easily add new features and modify existing code.
- **Reliability**:
  - The system shall function consistently without crashes.
  - The system shall allow players to resume gameplay after disconnection.

5.2 Use Cases

In this section, a use case diagram highlighting the primary functionalities of the system is presented. This diagram provides an abstract representation of the main use cases for each player, focusing on high-level actions rather than detailed implementation or workflow processes. The use case diagram is particularly effective in illustrating the differences in interaction between the two users. This abstraction allows for a generalized view of the system, than can clearly distinguish the role of each player in the game.

To enhance readability, the use case diagram has been created using a colour-coded scheme to categorize the actions according to their context within the system. The colour coding is as follows:

- **Blue background**: Represents actions associated with Aqua's mini-game.
- **Yellow background**: Highlights actions specific to Electro's mini-game.
- **Green background**: Portrays actions related to Verdis' mini-game.
- **White background**: Indicates general use cases that are not tied to any specific game character.

Next, we will further explain each of the use cases illustrated in the diagram.

UC1 - Create Room: This use case allows the adult player to create a room by entering a name, which the system uses to identify the game session in the game lobby (room list). Once the room is created, the adult player will automatically join as the host (master client). The room is listed in the lobby allowing the child player to find and join.

UC2 - Join Room: The child player can join a room by selecting one from the lobby's list of available rooms. Once the room has two players, it is removed from the room list to prevent additional joins. This feature ensures that only the intended players participate in the session, maintaining the game's focus on collaborative gameplay between an adult and child.

UC3 - Initiate Game: When both players are in the room, the adult player is provided with an option to start the game. Upon selecting this option, both the adult and child player are transported to the first game scene. This ensures that the game begins only when both players are ready and connected, making sure that the experience is synchronized.

Figure. 35: Use Case Diagram

UC4 - Start the Actual Game: This use case allows the child player to start the actual game. In the first game scene, both players will see a dark forest, but only the child player will see a shinning star that represents Perla, the first game character that the players will meet. As soon as the child presses it, the narrative sequence is triggered and the game transitions into the core gameplay. This mechanic actively engages the child in starting the game, possibly fostering a sense of immersion and responsibility.

UC5 - Change Story Scenes: To ensure that the narrative progresses at a steady pace, only the adult player has control over advancing the story scenes. This design prevents the child from accidentally skipping and makes sure the players will not miss any important information.

UC6 - Rotate the Pipes: In Aqua's Connecting the Pipes mini-game, the adult player solves each of the puzzles by rotating individual pipes to establish a complete connection for the water to flow.

UC7 - Clean/Fix the Pipes: This use case allows the child player to navigate the puzzle grid to clean and/or repair the pipes. Using the provided tools, the child player can use the broom to clean the spider webs or the wrench to fix the cracks, ensuring the pipes are functional. While the adult player does not complete the puzzle, these issues will reappear periodically, requiring the child to clean or repair again. This mechanic fosters teamwork and encourages communication between players to achieve success.

UC8 - Spawn Suns: This use case refers to phase one of Electro's mini-game. The adult player must strategically spawn suns so that the child player can catch them and score points for both.

UC9 - Catch Suns: This use case allows the child player to participate in phase one of Electro's mini-game by using a movable solar panel to catch suns spawned by the adult player. This mechanic encourages dexterity and spatial awareness from the child, while fostering collaboration with the adult to maximize the score.

UC10 - Place Solar Panels: The adult player is responsible for placing the solar panels in strategic locations during the second phase of Electro's mini-game. By observing the environment, the adult identifies the optimal locations to place these solar panels to maximize sunlight capture. The optimal locations to place the solar panels will change, so the adult has to pay attention.

UC11 - Remove Clouds: This use case is only applicable to the child player, as they will have to remove the clouds that obscure the sunlight. If the clouds are not removed, the adult player will not be able to see where the best locations to place the solar panels are.

UC12 - Remove Fires: This use case is related the role of the adult player in Verdis' mini-game. The adult must extinguish the fires so that the trash will not burn. This will then give the child a chance to recycle it correctly.

UC13 - Catch Trash: The child player will take on the task of catching the trash, but they do not know what the current recycling bin is. They will have to rely on the adult player to correctly inform them of what the bin currently is.

UC14 - Select Quiz Answer: Both players should communicate to answer each question in the quizzes, but only the adult player has the ability to chose the answer. Once selected, the system provides immediate feedback.

UC15 - Investigate Renewable Energies on Madeira Island: This use case introduces an exploratory task where players learn about some of the renewable energy sources on Madeira Island. Players navigate an interactive map of the island, in which they will be able to see multiple photos of different initiatives taking place across the island. This mechanic encourages curiosity and discussion about renewable energy solutions and their real-world impact.

UC16 - Game Character Photo: This use case refers to the last section of the prototype game, in which players are prompted to take a picture with the game characters. This feature allows players to create a memorable and interactive experience.

5.3 UML Diagrams

Unified Modelling Language (UML) activity diagrams are a useful tool for modelling the dynamic behaviour of a system. These provide a structured representation of the flow of actions and decision points, making them an effective way to visualize the logic applied behind game mechanics. For *Mystiria*, we have created UML activity diagrams for each of the mini-games.

Aqua's mini-game UML diagram, as seen in Fig.36, outlines the sequence of actions involved in managing water flow in the pipes. For example, even if the current pipe is in the correct position and is cleared of any spider webs or cracks, it will not receive water unless the previous pipe in the sequence already contains water.

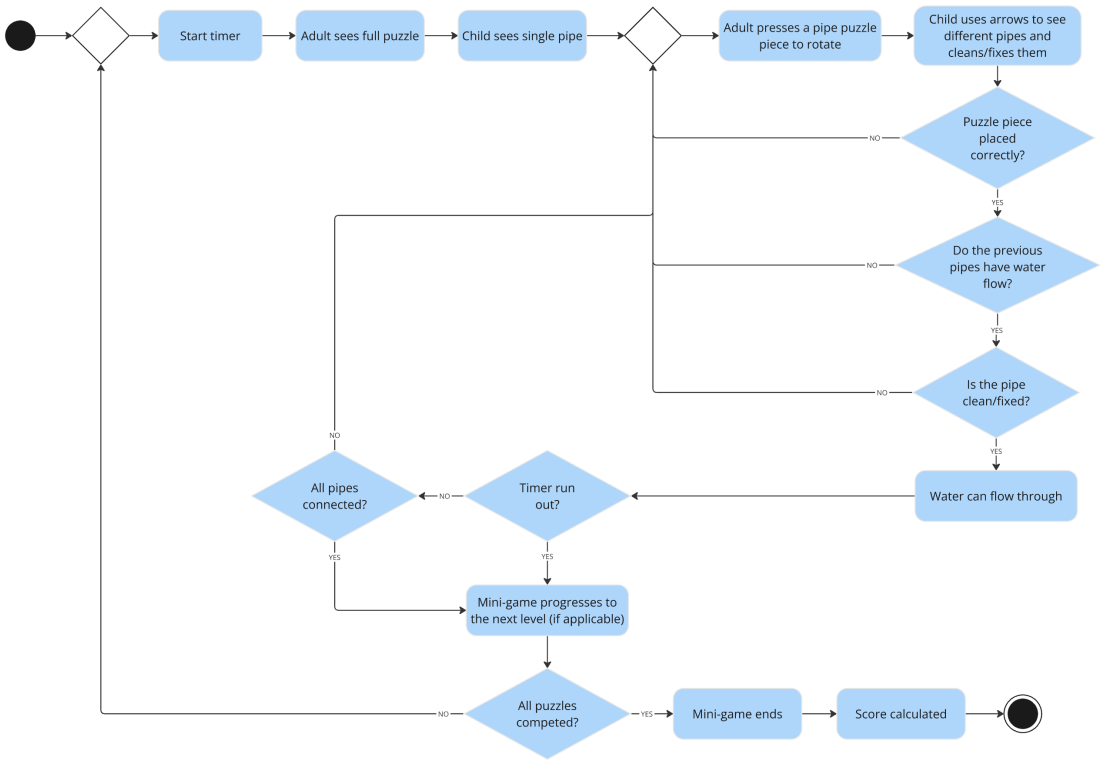


Figure. 36: Activity UML for Aqua's Mini-game

Electro's mini-game UML diagram, illustrated in Fig.37, combines both phases. It shows the rationale behind phase 1 and reflects the decision making process for placing and adjusting the solar panels, as well as the conditions that determine if the panels are placed correctly or not.

Verdis' mini-game UML diagram, portrayed in Fig.38, models how players must correctly sort trash into the recycling bin.

Having established the sequence of actions and interactions in the mini-games through UML activity diagrams, it is essential to compliment these with a representation of the structure of the game's architecture. Since *Mystiria* was developed in Unity, where GameObjects are directly linked to scripts, a simple UML class diagram may not fully convey the interplay between visual elements and the code. To tackle this, we present UML class diagrams overlaid in game screenshots, which provide a more intuitive and contextualized understanding of how the GameObjects interact and work in the game.

The main classes in Aqua's mini-game are displayed in Fig.39. We focused on the key attributes and methods to facilitate a deeper understanding of the structure and functionality.

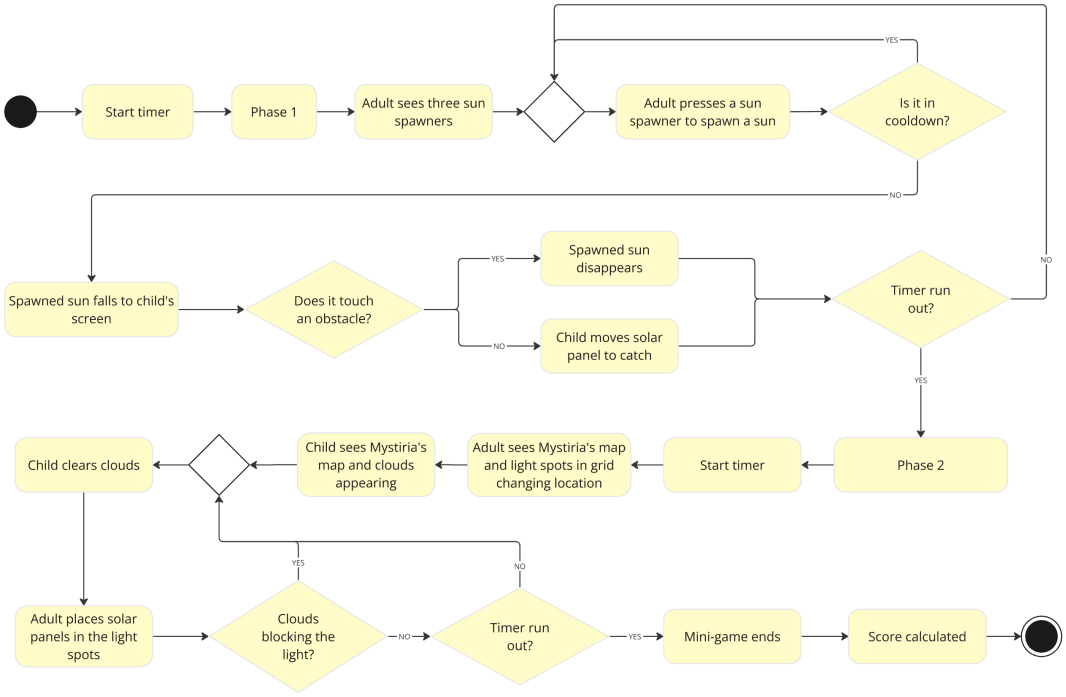


Figure. 37: Activity UML for Electro's Mini-game

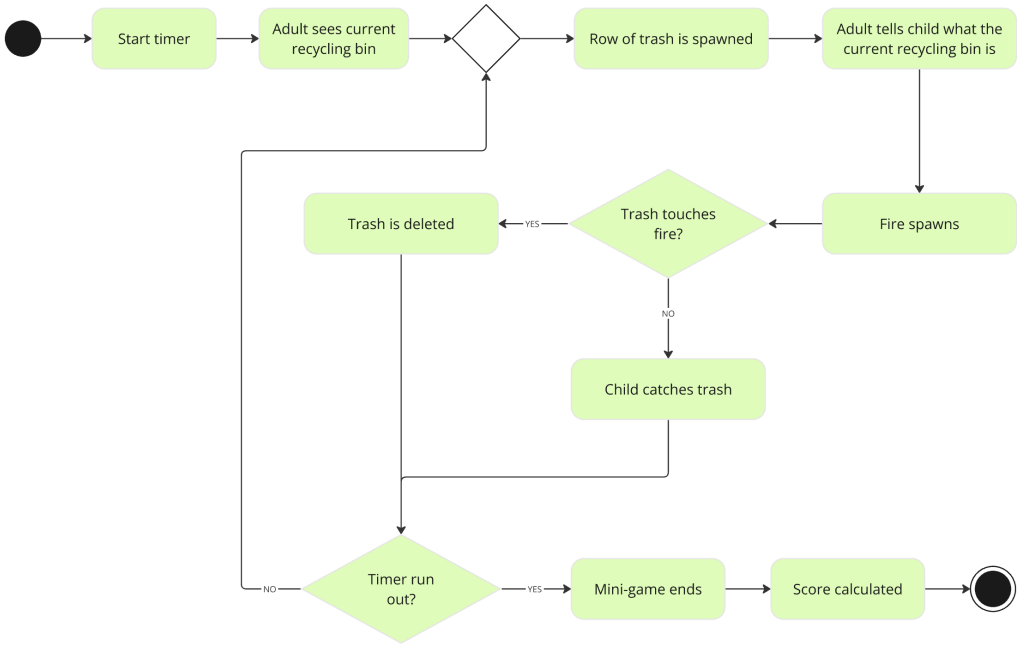


Figure. 38: Activity UML for Verdis' Mini-game

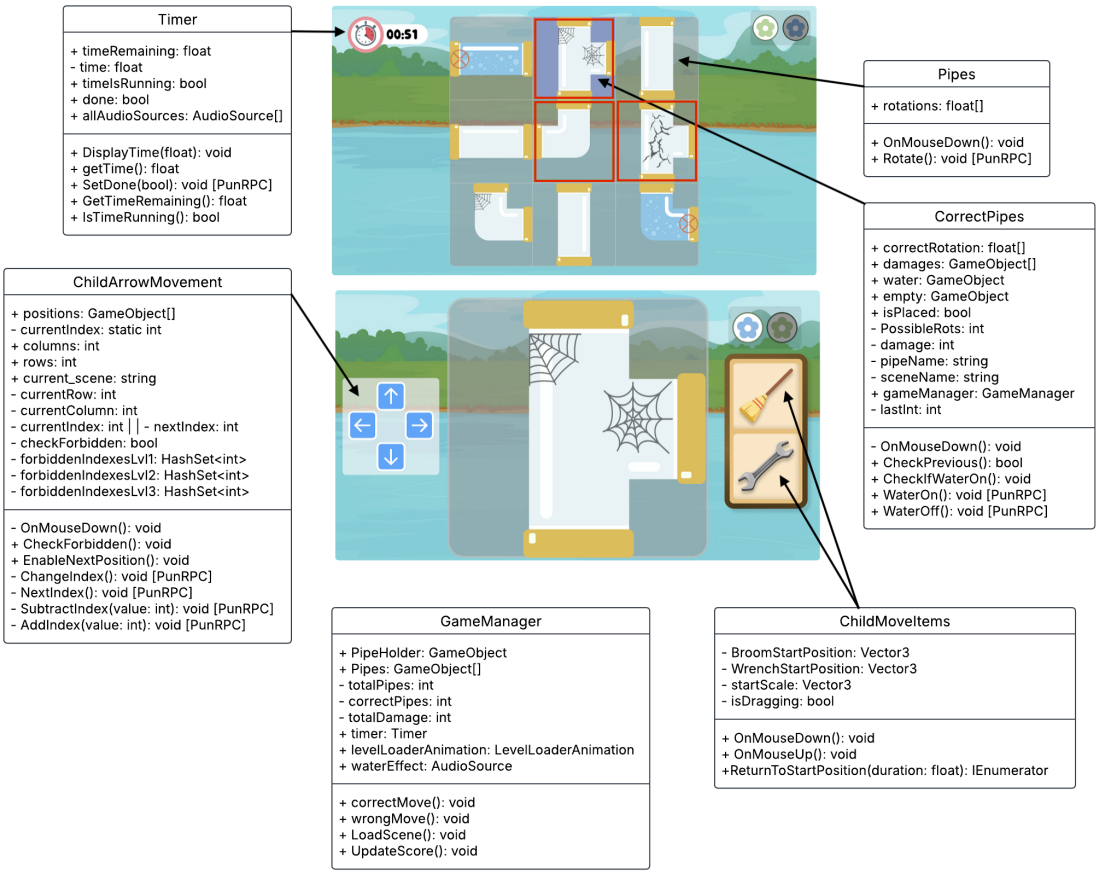


Figure. 39: Class UML for Aqua's Mini-game

The ***Timer*** class is responsible for managing the countdown timer and is present in all of the mini-games. In this class, when the time left on the countdown reaches 10 seconds a sound will be played to alert that players are running out of time. The *SetDone* is a PUN Remote Procedure Call (RPC) method that synchronizes when the timer is finished across all players in the game.

The ***ChildArrowMovement*** class handles the movement of the child player through the puzzle and is applied to each of the arrows (left, right, up and down). Based on the *current_scene*, this class will initialize with different values for the number of *columns* and *rows*. When the child player interacts with the arrows, the method *CheckForbidden()* is responsible for the validation of the movement and, if the movement is possible, it will call *EnableNextPosition()*. Every single one of the three phases of this mini-game has "forbidden" positions that mean the child can not go there. These are simply the positions out of the array of the pipes. In the provided example, these are the first and last pipe (the ones that currently have water).

The ***GameManager*** class controls several aspects of the gameplay, including pipe placement, timer management and scene transitions. The class interacts with other components like the *Timer*, *LevelLoaderAnimation*, and *AudioSource* to manage the game flow and provide feedback to the players. The *correctMove()* and *wrongMove()* methods adjust the count of correctly placed pipes and trigger actions when the game reaches certain conditions, such as completing the puzzle or making a mistake. When all the pipes are correctly placed, and there's no damage, the timer stops, the water flowing sound plays, and the scene transitions to the next. This class also ensures that when all of the pipes are in the correct position, players will not be able to interact with them anymore.

The ***ChildMoveItem*** class handles the dragging functionality of the UI elements of the broom and wrench. It allows the child player to interact with these items by clicking and dragging them around the screen. When these objects are pressed, the script enables dragging and scales up the object to emphasise interaction. Upon releasing the object, it smoothly returns to its starting position and scale.

The ***CorrectPipes*** class is assigned to the pipes which are part of the solution (in this case those are the pipes with a red square around them). It will handle their rotation, correct placement and water flow. This class checks the condition of previous pipes to determine if water can flow into the current pipe, and updates the game state accordingly. The *correctRotation[]* array stores the only possible correct rotations for any given pipe. The class also interacts with a *GameManager* to keep track of correct and incorrect moves. The methods *WaterOn()* and *WaterOff()* use PunRPC because they will synchronize across players if the pipe has water flowing or not.

The ***Pipes*** class is responsible for managing the other pipe GameObjects. Its only job is the *Rotate()* method that rotates the pipe 90^{o} every time it is pressed.

As previously mentioned, Electro's mini-game is divided in two different phases. The first phase is shown in Fig.40 and it shows the main classes used.

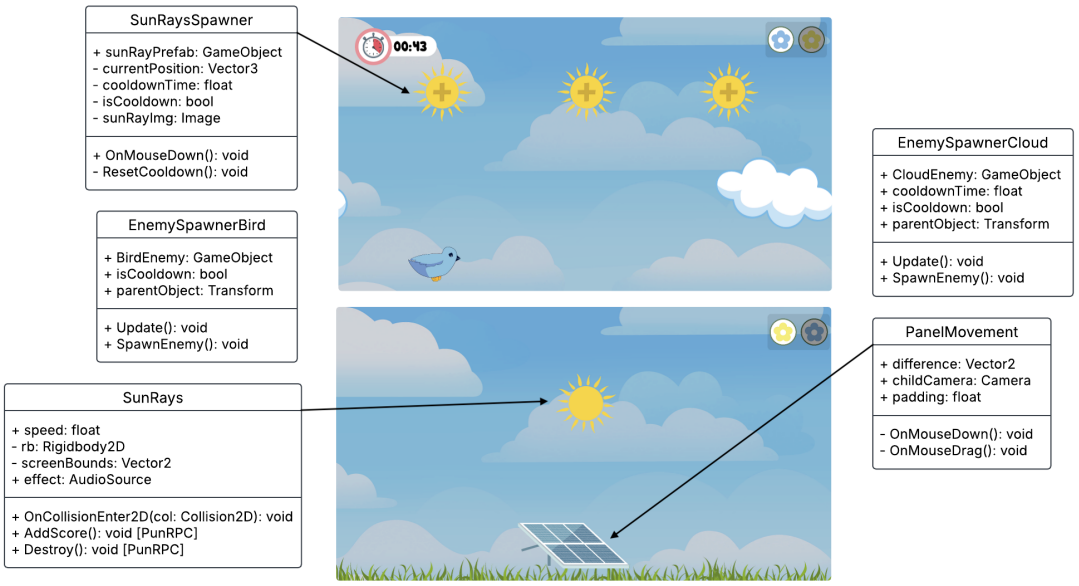


Figure. 40: Class UML for Electro's Phase 1 of Mini-game

The ***SunRaysSpawner*** class manages the spawning of the SunRay objects when they are pressed by the adult, with a cool down of 1.5 seconds. When a player clicks on this object, a SunRay is instantiated and the object's transparency is adjustd to provide visual feedback.

The ***EnemySpawnerBird*** class is responsible for spawning the bird enemies at random intervals between 7 and 15 seconds. It is attached to a GameObject outside of the scene.

The ***SunRays*** class is attached to every spawned SunRay object and uses the photon networking capabilities to ensure it is synchronized on all players. This class also ensures the sun keeps falling down in a controlled motion, unless it comes in contact with another GameObject, in which case it gets deleted.

The ***PanelMovement*** class allows the child players to move the solar panel horizontally within a set screen limit.

The ***EnemySpawnerCloud*** class is responsible for spawning the cloud enemies at a constant rate of 7 seconds.

The second phase of Electro's mini game is depicted in Fig.41.

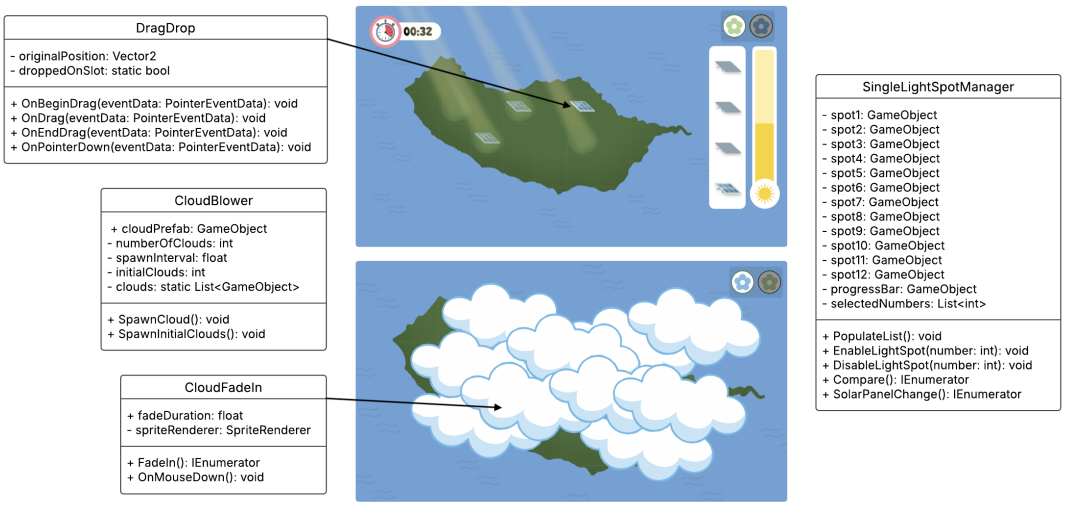


Figure. 41: Class UML for Electro's Phase 2 of Mini-game

The ***DragDrop*** class enables the drag and drop functionality of the solar panels. The *OnPointerDown()* method detects when the adult player clicks on the solar panel GameObject, the *OnBeginDrag()* reduces the panel's transparency and disables raycasting to allow proper slot detection, the *OnDrag()* moves the panel based on the cursor's movement and the *OnEndDrag()* restores transparency and checks if the panel was placed in a valid slot. If not, it returns to its original position.

The ***CloudBlower*** class manages the spawning of the cloud GameObjects. New clouds are periodically spawned at random positions in predefined boundaries. It also ensures that new clouds are placed sufficiently far from existing ones to avoid overlap, with a limit on the number of attempts to find a valid position.

The ***CloudFadeIn*** class handles the gradual fade-in effect of a cloud object and allows players to delete clouds by clicking on them. When instantiated, the cloud starts fully transparent and gradually becomes visible over a set duration (*fadeDuration*) using a coroutine.

The ***SingleLightSpotManager*** class controls the management of the different light spots that appear and disappear randomly over time. The multiple GameObject spots represent the twelve different locations that the light spots can shine in. In total, there are always four different light spots shinning, in which the adult player can place the solar panels. The *SolarPanelChange()* method is a coroutine that periodically changes the location of one randomly selected light spot,

while the *Compare()* method compares the current light spots with the position of the solar panels, updating the total score and progress bar accordingly.

To conclude, Fig.42 illustrates Verdis' mini-game, with its main classes.

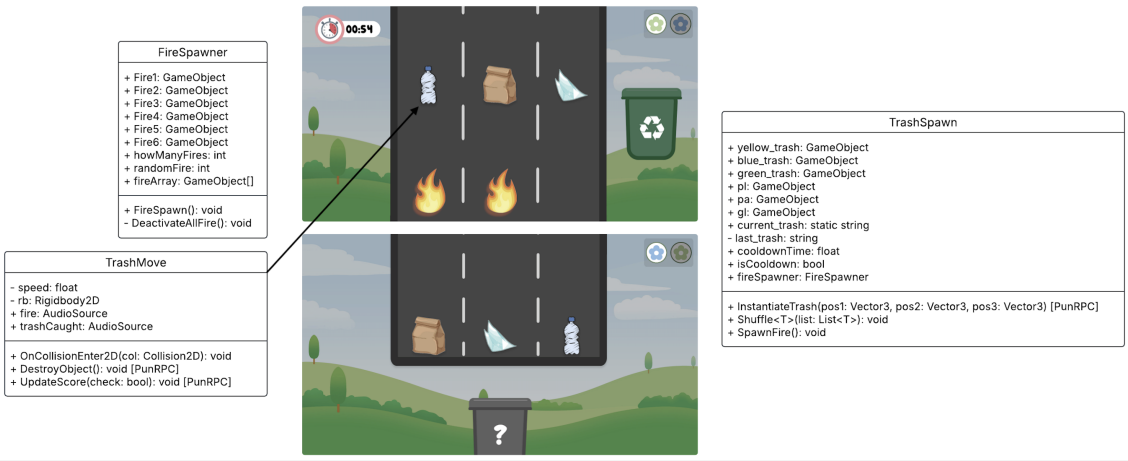


Figure. 42: Class UML for Verdis' Mini-game

The ***FireSpawner*** class manages the activation of the fire GameObjects. It will initialize an array of predefined fire objects, ensuring they are all inactive to begin with. The *FireSpawn()* method triggers a one second delay to then randomly determine how many out of the three fires will be activated.

The ***TrashMove*** class is responsible for the movement and interaction of the trash objects. The rigid body component applies a downward movement to the trash. The class also manages collision interactions, checking if the trash collides with the correct bin (based on the current recycling category) or enemies such as fire. If a player correctly sorts the trash, they receive points, whereas incorrect sorting results in a penalty. The class uses PhotonView to synchronize destruction across the network and update the score consistently across all players. Audio feedback is also included for correct sorting and collisions with fire.

The ***TrashSpawn*** class is responsible for spawning the trash objects, every few seconds, in random order (Plastic, Paper and Glass). It also manages the *current_trash* which can either be blue, yellow or green. These colours represent the different recycling bins we have in Portugal.

5.4 System Architecture

The project's structure has been organized to facilitate finding the code, being easily scalable and maintained. The project is divided into the following main directories:

- **Directory "Animations"**: This directory contains all of the animations used in the game, from the fire, text, scene changes, score and more.
- **Directory "Images"**: Stores all of the images used in the game, from the logos, backgrounds, game characters, objects, icons and more, all of them neatly organized in sub-directories.
- **Directory "Fonts"**: This directory is used to organize the different fonts used in the game.
- **Directory "Scenes"**: Contains all of the game scenes and is further divided in *0_Perla*, *1_Aqua*, *2_Electro*, *3_Verdis*, *4_HomeScreen* and *5_MadeiraIsland*.
- **Directory "PhotonPrefabs"**: In Unity, prefabs are reusable GameObject templates that store a preconfigured set of components and properties. They allow the creation of multiple instances of the same object while maintaining consistency. In this case, the prefabs are used to create the menus for *PlayerListing* and *RoomListing*.
- **Directory "Resources"**: In this directory the game's prefabs are stored. Some of the game's objects, such as the clouds, trash and spawned rays, have to be a prefab otherwise they will not synchronize between players.
- **Directory "Scripts"**: In this directory, all of the scripts for the different components of the game are present. For a better organization and to facilitate code scalability and management, this directory is subdivided into *0_Perla*, *1_Aqua*, *2_Electro*, *3_Verdis*, *4_Photon*, *5_Localization* and *6_Others*.

The architecture of *Mystiria* follows a Model-View-Controller (MVC) inspired structure. The **Model** layer is composed of resources such as prefabs and photon managed objects. The **Controller** handles data logic, implemented through the scripts that control mechanics, interactions and networking. The **View** is responsible for presenting the data the controller sends, and consists of the animations, scene layouts, UI elements, images and fonts that define the game's visual presentation.

6 Implementation

For this chapter, we will focus and provide details on the more technical and unconventional aspects of *Mystiria*. We will explore the technologies used to create a multiplayer game with various language adaptations. The following sections elaborate on these components, detailing their implementation and role in *Mystiria*.

6.1 Multiplayer Networking

Multiplayer networking is the backbone of this project as it enables player to connect and interact in real-time, fostering ACI. This requires managing synchronization, communication, and data transfer between multiple clients (players) and often a server, ensuring a consistent gameplay experience. For this project, multiple frameworks were evaluated, but Photon PUN (Photon Unity Networking) was chosen.

Photon PUN is a real-time multiplayer framework for Unity that provides developers with tools to create and manage networked gameplay experiences. It simplifies the complexities of creating a multiplayer network, such as synchronization, matchmaking and data transmission between players.

The first step in order to access these functionalities is to create an online Photon server, which provide an API key to create a connection between the game and online server. To link a Unity client to the Photon server, the code portrayed on line 24 of Fig.43 has to be used.

```
16      private void Start()
17      {
18          // Set the internal rendering resolution to 1920x1080
19          Screen.SetResolution(1920, 1080, false);
20
21          PhotonNetwork.AutomaticallySyncScene = true;
22          PhotonNetwork.GameVersion = MasterManager.GameSettings.GameVersion;
23          print("Connecting to server...");
24          PhotonNetwork.ConnectUsingSettings();
25      }
```

Figure. 43: Connecting to Photon PUN's Server

In Photon PUN, a room is a virtual space in which players can interact with each other. A room is also used to host a specific multiplayer session. Players are able to create and connect these rooms. After successfully connecting to the server, players will be given the opportunity to create or join an existing room. The method that allow players to create a room is illustrated in Fig.44.

```
18      public void OnClick_CreateRoom()
19      {
20          if (!PhotonNetwork.IsConnected)
21          {
22              return;
23          }
24
25          //removes the zero width space
26          string cleanedRoomName = _roomName.text.Replace("\u200B", "");
27
28          if (string.IsNullOrWhiteSpace(cleanedRoomName))
29          {
30              Debug.Log("Room name cannot be empty.", this);
31          }
32          else{
33              RoomOptions options = new RoomOptions();
34              options.MaxPlayers = 2;
35              options.CleanupCacheOnLeave = false;
36              options.PlayerTtl = 100000;
37              PhotonNetwork.JoinOrCreateRoom(_roomName.text, options, TypedLobby.Default);
38          }
39
40      }
```

Figure. 44: Room Creation Method

First, the code checks if the players are actually connected to the Photon server. Then, on line 26, the room name is "cleaned" to ensure that there are no zero-width space characters (Unicode `\u200B`) as these invisible characters were causing problems when trying to show the room name in the User Interface (UI). After cleaning the name, the code checks whether it is empty, null or only consists of white spaces. If any of these are the case, then the room will not be created. If it is valid, a room will be created with the following conditions:

- A maximum of 2 players are allowed to join the room, the child and the adult. Once this number is reached, the room will not be listed anymore.
- By setting the *CleanupCacheOnLeave*, we are ensuring that the room's state will not be cleaned up when players leave. This setting is particularly useful to ensure that a player is able to return to a room in case they leave mid-game.
- *PlayerTtl* is time-to-live for all the players in the room in milliseconds. This means that if a player is not connected to the room for 100 seconds, they will automatically be removed.

Typically, only the adult player will be able to create a room, becoming the MasterClient. The child becomes the Client when they join a room. This difference is particularly useful when designing mini-games and giving each player a role, as they can quickly be checked and assigned based on who is the MasterClient or not.

When a child wants to join a room, it is visible in the main lobby, where the rooms are shown in the room list. To achieve this, two main classes are used, *RoomsListingMenu* and *RoomListing*.

These two classes manage the display and interaction with available rooms, providing the required functionalities for listing, joining and updating room information.

6.1.1 ScriptableObject Singleton

The singleton design pattern ensures that a class has only one instance and provides a global access point to it. This is particularly useful when managing shared data and/or configurations that must persist and remain consistent throughout the application.

A ScriptableObject singleton is a design pattern in Unity that combines the benefits of a singleton and a ScriptableObject to manage globally accessible and persistent data efficiently without relying on GameObjects or scene dependencies. This approach is particularly useful for managing configuration settings and shared resources that need to be accessible across the application.

An example of this design pattern is used on the *MasterManager* class (see Fig. 45). This method inherits from *SingletonScriptableObject*, so it ensures that only one instance of *MasterManager* exists in the whole project. This proved useful as it created a global access to the *GameSettings*, as shown on line 22 in Fig. 43.

```
10  [CreateAssetMenu(menuName = "Singletons/MasterManager")]
11
12  public class MasterManager : SingletonScriptableObject<MasterManager>
13  {
14      [SerializeField]
15      private GameSettings _gameSettings;
16
17      public static GameSettings GameSettings { get { return Instance._gameSettings; }}
18
19  }
```

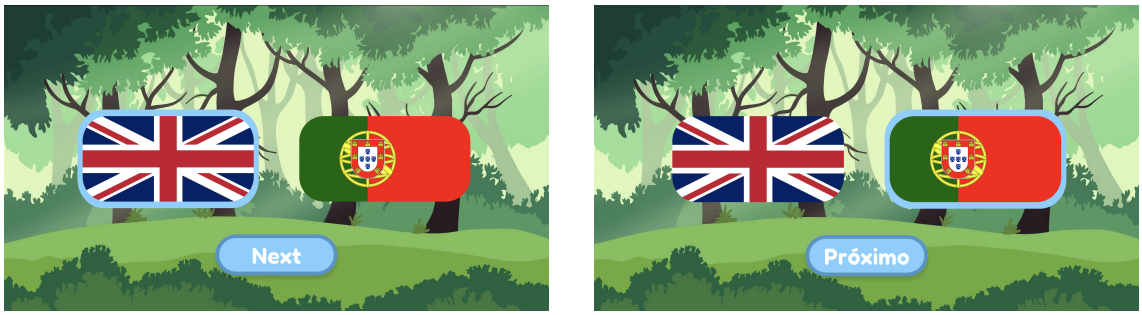
Figure. 45: *MasterManager* Class

Using a ScriptableObject singleton, like the *MasterManager* (Fig. 45), exemplifies best practices when developing. This implementation ensures data persistence and simplified debugging. By separating concerns and centralizing the *GameSettings*, it has contributed to maintainable and scalable code, that can be easily understood if needed in the future.

6.2 Unity Localization

The game can either be played in English or in Portuguese, through the use of a Unity asset called Localization Tables. This asset allows for the language in the game to be easily switched. The

players simply have to pick which language they prefer in the beginning of the game, depicted in Fig. 46.



(a) English **(b)** Portuguese

Figure. 46: Language Selection

In order to allow the game to be played in multiple languages we have looked at different approaches, but Unity's Localization was the best option. This package allowed us to store, manage and access the game content in different languages. For the current project, we translated to English and Portuguese, but in the future, additional language support can be included.

To ensure this selection persists throughout the entire game, line 66 in Fig.47 is mandatory. This updates the selection of the language at the core of the game, based on the *_localeID* passed. For English, this variable is 0 and for Portuguese it is 1.

```
61      IEnumerator SetLocale(int _localeID){
62          active = true;
63          //make sure localization is loaded and ready to be used
64          yield return LocalizationSettings.InitializationOperation;
65
66          LocalizationSettings.SelectedLocale = LocalizationSettings.AvailableLocales.Locales[_localeID];
67
68          active = false;
69      }
```

Figure. 47: String Array for Localizes String Keys

The primary method for achieving localization in Unity is through the use of Localization Tables, which are containers for different types of localized data, such as text, audio or images. In our case, we only used this for text. As illustrated in Fig.48, we defined a key and then provided the specific text for each of the languages we wanted our game to have.

These tables are designed to be editable both through the Editor and Runtime, making them flexible for dynamic content changes and debugging.

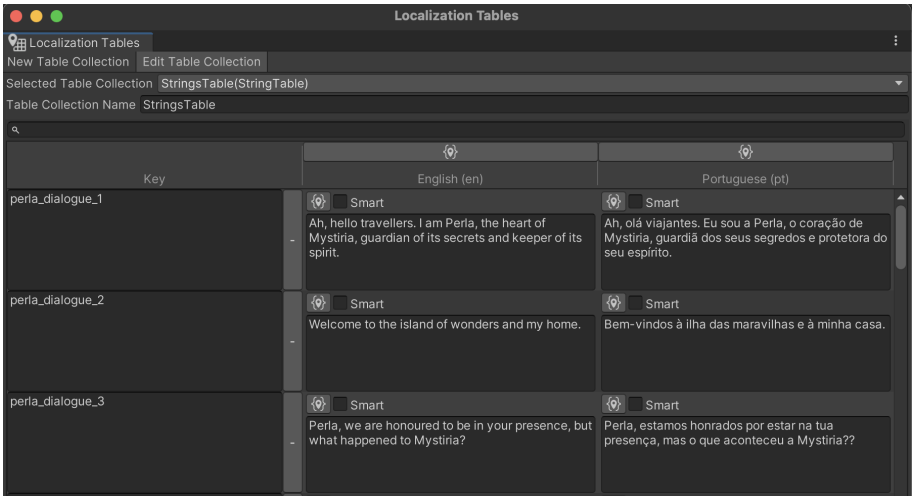


Figure. 48: Example of a Localization Table in Unity

Some scenes in our game, particularly the narrative ones, feature a Typewriter effect applied to the text to contribute to the game's atmosphere, pacing and engagement. Other scenes, such as the quiz ones, displayed static text without animation. This difference required adjustments to the implementation of the Localization Tables to accommodate the specific needs of each case.

When the goal was to just show the text, a component was added in the inspector to the specific game object that displayed the text. In this component, the Localize String Event illustrated in Fig.49, the string reference is the previously chosen table key, and the content is automatically retrieved.

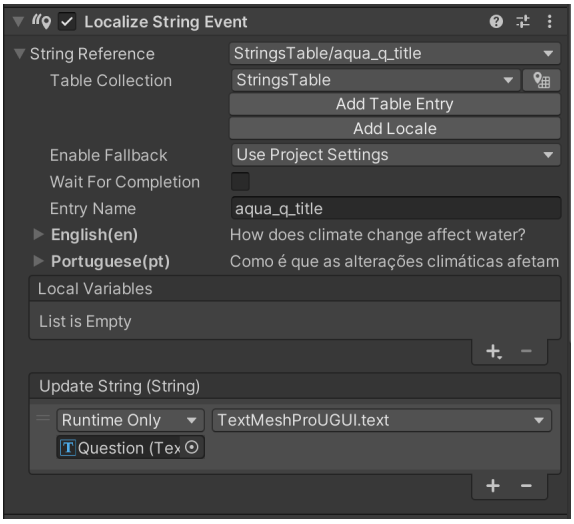


Figure. 49: Example of Unity Localization - Inspector

If the text had the Typewriter effect, the localization had to be done through code. To begin, we have implemented a *LocalizationManager* class that contains the methods shown in Fig.50. The method *GetLocalizedString()* retrieves an array of localized strings based on a given array of keys and returns them.

```
22      public string GetLocalizedString(string key)
23      {
24          return LocalizationSettings.StringDatabase.GetLocalizedString(key);
25      }
26
27      public string[] GetLocalizedStrings(string[] keys)
28      {
29          string[] localizedStrings = new string[keys.Length];
30          for (int i = 0; i < keys.Length; i++)
31          {
32              localizedStrings[i] = GetLocalizedString(keys[i]);
33          }
34          return localizedStrings;
35      }
```

Figure. 50: Methods in the *LocalizationManager* Class

The call for this method is done inside the *TypewriterEffect* class, in the *Start()* method, as shown in Fig.51.

```
216         //Perla
217         if (sceneName == "PerlaNarrative")
218         {
219             StartCoroutine(ShowText(LocalizationManager.Instance.GetLocalizedStrings(perla_dialogue)[currentTextIndex]));
220         }
```

Figure. 51: Calling the Method *GetLocalizedStrings()* Example for Perla

```
28      private string[] perla_dialogue = new string[]
29      {
30          "perla_dialogue_1",
31          "perla_dialogue_2",
32          "perla_dialogue_3",
33          "perla_dialogue_4",
34          "perla_dialogue_5",
35          "perla_dialogue_6",
36          "perla_dialogue_7",
37          "perla_dialogue_8",
38          "perla_dialogue_9",
39          "perla_dialogue_10",
40          "perla_dialogue_11",
41          "perla_dialogue_12",
42
43      };
```

Figure. 52: String Array for Localized String Keys

The provided example is for the Perla narrative. Since the narrative is only shown in one scene and the text changes, we had to create an array that stored the keys for the texts in the localization

tables, see Fig.52. Each of the strings inside the array represent a key in the localization table, which will then be retrieved and showed on the players' screens.

6.3 Pilot Test

Prior to conducting the user tests, two pilot tests were undertaken to evaluate the prototype's gameplay, game mechanics and overall usability. These pilot tests aimed to identify potential issues, ensure that the game mechanics were intuitive and engaging for players and verify that the game interface provided a seamless experience. These tests were performed with four different adults, two at a time, to simulate an adult and a child interacting with the game. For each of the pilot tests, the players would play the game and then take part in a quick interview.

There was a slight difference between the two pilot tests. For the first one, players got straight into the game, but on the second one we showed the players a quick explanation of the game.

From the pilot tests, we gathered the following feedback:

Key Observations

- Gameplay Collaboration
  - Players appreciated the cooperative nature of the game, requiring communication and joint effort to complete the mini-games.
  - The design was praised for fostering interaction between the adult and child players.
  - Participants found the game engaging, informative, and appropriately timed.
- Game Context and Storyline
  - Participants found the context and storyline meaningful and connected well with the mini-games.
- Challenging Aspects
  - Certain game mechanics, such as clicking on fires to make them disappear or understanding the adult's and children's roles in some tasks, were initially unclear.
- Topics Addressed
  - Players identified the key sustainability topics in the prototype: water conservation, renewable energy and recycling.

- The educational elements of the game, such as the quizzes and certain visuals, provided valuable context on climate change and sustainability.

Suggested Improvements

– User Interface Improvements

- Add a "mouse over" effect or highlight on the island icons to make the clickable areas stand out.
- Ensure clarity during specific actions, such as informing players whose turn it is or providing instructions for ongoing tasks.
- Consider platform adjustments, like enabling gameplay on mobile devices.

– Tutorial Improvements

- Clarify the distinct roles and views of the adult and the child in the tutorial.

– Bug Fixes

- Fix a visual glitch where the trash appears under the road on specific computers.

In the comparative observations between both pilot tests, the initial game explanation video showed that it helped players communicate more effectively, which contributed to smoother gameplay. Both pilot tests highlighted the importance of cooperation and communication needed to be successful in the game. Additionally, participants in both tests recognized the game's emphasis on sustainability topics and the educational aspect mixed in with the mini-games.

From the invaluable insights and feedback provided from these tests, we implemented the following changes to the prototype:

– Improved the game narrative;

– Added the "mouse over" effect on interactive elements, to guide players more intuitively;

– Enhanced tutorial instructions to specify roles, specific tasks and what each of the players will see;

– Updated the code to ensure that the game window opens with a predetermined and specific window size.

7 User Evaluation

User evaluation is an important step in assessing the effectiveness, usability and overall impact of the game. This chapter aims to provide a comprehensive overview of the user study, including protocol, measures and how the data will be analysed, followed by an assessment of the gathered results.

7.1 Study Design

Given the nature of our game prototype and the type of interaction required, we have adopted a mixed-methods approach, integrating the analysis of quantitative and qualitative data. A pretest-posttest design was specifically applied to the adult participants, allowing for an assessment of changes in environmental knowledge, attitudes and engagement before and after gameplay. The pretest provided baseline data on participants' understanding of climate change and sustainability, while the posttest enabled the identification of potential shifts in perceptions and awareness.

This mixed-methods approach enabled us to gain a deeper understanding of the user experience and ACI, and to identify areas of strength and weakness.

Our study has been approved by the Ethics Committee of the University of Madeira with the code P161.

7.2 Protocol and Metrics

In this section, we will outline how the data was gathered and processed to evaluate the game's design, usability and impact. The mixed-methods approach includes the following data:

- **Quantitative Data**:
  - **Pretest-Posttest Questionnaires**: To measure changes in players' knowledge or attitudes related to climate change and sustainability before and after gameplay.
  - **In-Game Metrics**: To analyse player behaviours, including score for each mini-game, answers for the quizzes and time taken to complete the game.
- **Qualitative Data**:
  - **Observations**: During the play sessions, researchers took notes on player interactions, communication dynamics, comments and any difficulties encountered.

- **Semi-structured Interviews**: After the game, participants took part in guided interviews where they could share more details about their experience, providing insights into their perceptions of the gameplay, educational aspect, communication effectiveness, possible improvements and overall satisfaction. By gathering open-ended feedback, we hoped to gather a deeper understanding of the player's perspectives compared to solely relying on standardized scales.

Initially, the study was designed for a larger sample size, however due to practical constraints, the final sample consisted of 12 participants. Given this limitation, while a mixed-methods approach was employed, this analysis will emphasise the qualitative data. Quantitative data will be statistically described instead of being submitted to a statistical analysis, serving as a complimentary measure to support the qualitative findings. As our analysis employs a mixed-methods approach with a greater focus on qualitative data, this sample size is considered adequate to capture the gameplay experience and explore in-depth the interactions, perceptions and dynamics betweens players, making it possible to have a detailed comprehension of the involved aspects.

The participants of our study - 6 adults and 6 children (parents and children) - were directly approached and were not remunerated for participating. They were selected based on their availability, willingness to participate, being over 18 years old (for the adult), being between 6 and 10 years old (for the child) and the ability to interact with a computer game.

The user study sessions lasted around 1 hour and 10 minutes. Following protocol, on arrival, the study was briefly explained to the participants (in terms of structure and without disclosing information that would hinder interaction and gameplay) and adult participants were given the informed consent form and the declaration of consent for minors.

When both consent form were signed, adult participants completed a pre-game questionnaire that collected demographic data (participants' gender and participants' age), had a question to categorize the usual games that the adult plays with the child, and evaluated the knowledge of the adult in regard to climate change. To further understand their position towards environmental concern, we also included the revised New Environmental Paradigm (NEP) [85] scale. The adult's knowledge on climate change and sustainable practices was assessed using Likert-scale items with five levels, ranging from "Strongly Disagree" to "Strongly Agree", for the following statements:

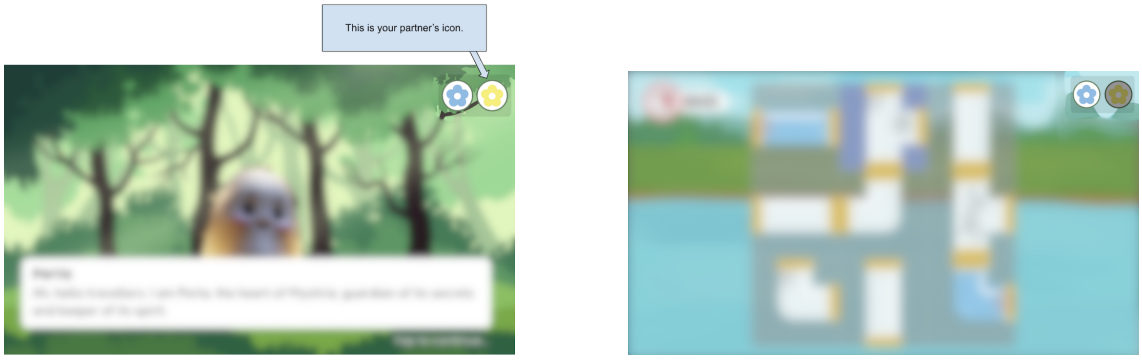
– 1) Climate change is caused by human activities

- 2) It is essential to reduce fossil fuel consumption to mitigate climate change.
- 3) Consequences of climate change are already affecting people in various parts of the world.
- 4) Recycling regularly at home can significantly contribute to reducing pollution.
- 5) The best way to reduce carbon emissions is to use renewable energy sources like solar and wind.
- 6) Behavioural changes in an individual, such as saving water and electricity, can have a significant impact on the environment.
- 7) Adopting sustainable habits in a person's day to day life is easy for the majority of people.
- 8) Climate change will have a bigger impact in the next generations compared to ours.

The full pre-game questionnaire can be found in the Appendix C, from Fig.**??** to Fig.**??**.

After completing the pre-game questionnaire, players were introduced to a tutorial that provided an overview of the game's logic. This is detailed on Appendix A from Fig.**??** to Fig.**??**. The researcher also explained that the adult player would be responsible for advancing the narrative and transitioning between scenes.

Additionally, the researcher informed the participants that the icons on the top right corner represent both players in the game. If the icon on the right appears gray, it indicates that the other player is viewing a different screen from the current player, as illustrated in Fig.53. In particular, during the mini-games, this mechanic helps players recognize when they are experiencing different content.



(a) Both Players Are Seeing the Same Scene **(b)** Players Are Seeing Different Scenes

Figure. 53: Images Explaining Icons on the Top Right Corner

While participants played the game, the researcher took notes in the observation table; these notes ranged from how well they completed the mini-games, adult-child interactions, comments made about the game, comments about players' real-life experiences and any hardships encountered. Participants interacted with the prototype game using the laptops provided by the investigators. Since it is a multiplayer game, each participant had their own laptop to play in.

After the game, the adult participants were asked to fill out the post-game questionnaire while the child drew on a sheet of paper based on the following prompt "Draw your favourite character from *Mystiria* and show how they are helping fight climate change and saving the planet!" (see Appendix F for the drawings). This post-game questionnaire included some of the same items from the pre-game questionnaire, such as the questions to evaluate and categorize the knowledge of the adult in regards to climate change and the NEP scale to check for any differences post-intervention.

Additionally, the Social Presence Module is also part of the GEQ, and it evaluates social dynamics, including empathy, behavioural involvement, and negative feelings during cooperative play.

Even though, at first glance, it seemed prominent to include the Social Presence Module in the post-game questionnaire, we have decided against it. The GEQ was only used in the adult participants to ensure reliability, given the cognitive demands of the questionnaire. Consequently, even if we were to use the Social Presence Module it would be one-sided, limiting its usefulness in assessing the cooperative dynamics between the players. Due to this, we have decided to assess the expected cooperation qualitatively, through gameplay observations and guided interviews.

The post-game questionnaire is outlined in the Appendix C, from Fig.**??** to Fig.**??**.

As a final step, participants engaged in a semi-structured interview designed to gather in-depth feedback on key aspects of the game. This interview focused on evaluating the communication dynamics required during gameplay, the main message characters wanted to convey to participants, identifying areas for improvement and exploring which elements participants found most enjoyable or challenging throughout the gameplay. The open-ended nature of the interview allowed for nuanced insights that can inform future iterations of the game, ensuring a more refined and engaging experience. The complete interview with the detailed questions is illustrated in the Appendix C Fig.**??**.

To conclude the user study, the child completed a questionnaire specifically tailored for them, illustrated in Fig.54. This questionnaire utilized a pictorial Likert scale, allowing the child to easily identify and rank their responses using smiley faces. This approach ensured that the child could provide feedback in an intuitive and engaging way, making it easier for them to express their thoughts and experiences about the game.

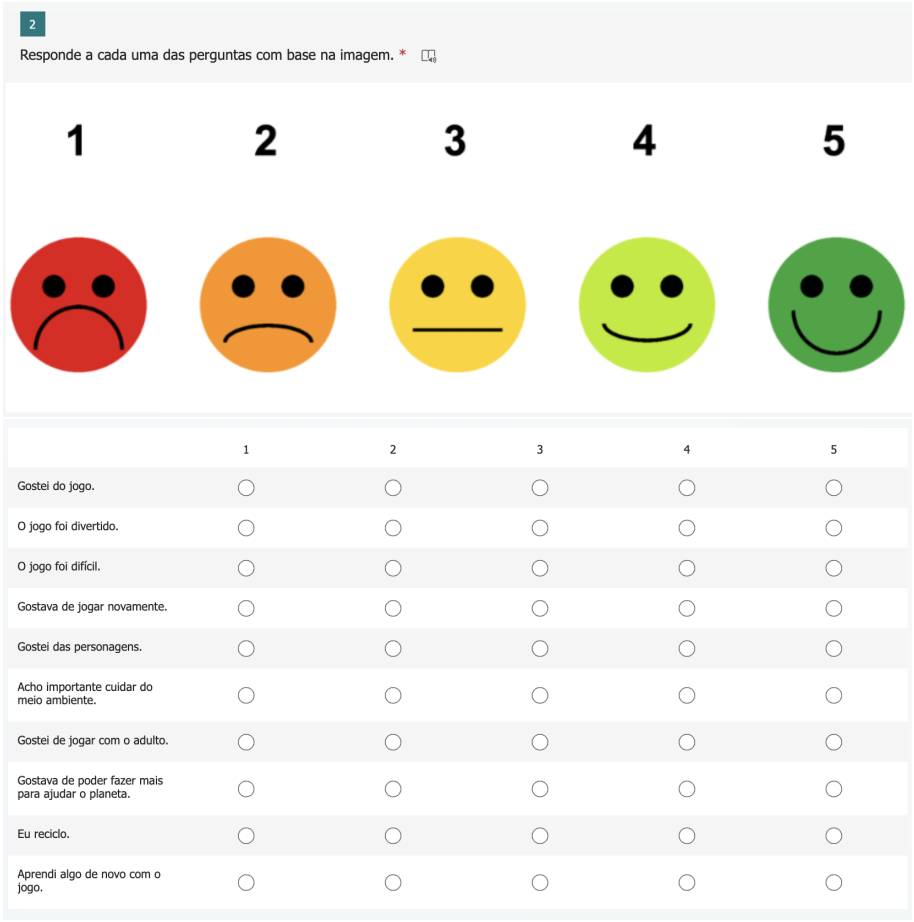


Figure. 54: Child Questionnaire

7.3 Data Analysis

In this study, the data analysis will be conducted using both Excel and Taguette[12], processing quantitative and qualitative data respectively.

Quantitative data will be analysed using Excel, focusing on the numerical data collected from the pretest-posttest questionnaires - which include the NEP and GEQ scales - , as well as in-game

[12] https://www.taguette.org/

metrics, providing a solid basis for evaluating participant's performance, progression and overall experience with the game, as well as their attitude and engagement with environmental themes.

Qualitative data will be examined using Taguette for a thematic analysis [94] of the semi-structured interviews which allows the identification of recurring patterns, players opinions and suggestions. The results gathered from this thematic analysis will be supplemented with information collected in the observation tables, offering insights into user engagement, enjoyment and ACI.

By combining these quantitative and qualitative methods, this evaluation seeks to answer the initially proposed research questions.

7.4 Quantitative Results

– **Demographics**

The demographic data obtained from the Pre-Game Questionnaire, shown in Table 3, offers valuable insights into gender distribution, age groups and game preferences, that can influence gameplay. Among the six adult-child pairs, female were predominant in the adult participants (5 female and 1 male) and child participants (4 female and 2 male). Adults ranged from 36 to 51 years old (M = 43,83 years old; SD = 6,65), while children were either 7 or 10. The games played between adults and children varied, but there was a strong inclination towards card games, which were played by almost all families. Younger children (7 years old) frequently engaged in outdoor/playground games and puzzles, while older children (10 years old) and their guardians preferred video games and card games. These findings show how important it is to include elements of teamwork, logic and interaction in game design, which align with the objectives of *Mystiria*.

– **Game Data**

As previously mentioned, for each of the user studies, we gathered the scores for the mini-games and the answers for each of the questions in the quizzes.

As scores are shared between adult and child, we do not identify the child and adult of each user study separately but as a pair; for example, user study 1 refers to the combined data for both the child and adult of that specific session. If needed, the actual questions can be consulted on Table **??**.

User Study	Adult's Gender	Child's Gender	Adult's Age	Child's Age	Games Played
1	Female	Male	49	7	Outdoor/Playground Games, Puzzles, Card Games
2	Female	Female	51	7	Puzzles
3	Female	Female	49	7	Video Games, Card Games, Outdoor/Playground Games
4	Female	Female	36	10	Video Games, Card Games, Puzzles
5	Male	Male	37	10	Board Games, Video Games, Card Games
6	Female	Female	41	10	Card Games, Outdoor/Playground Games, Puzzles, Video Games

Table 3: Demographic Data of the Players

Question	User Study						Percentage per Question
	1	2	3	4	5	6	
1							100%
2							83%
3							100%
4							83%
5							83%
6							100%
7							67%
8							83%
9							100%
	67%	89%	100%	100%	89%	89%	

Table 4: Correct Answers (Green) and Incorrect Answers (Red) with Calculated Percentages for the Quizzes

The results from Table 4 show that the majority of participants performed well across the questions. Questions 1, 3, 6 and 9 yielded 100% correct responses, suggesting that these topics were well understood by all players. Question 7 had a lower correct answer percentage, which may indicate that the topic was difficult, or the question was confusing.

Overall, the data suggests that while most of the topics were understood, a few questions could benefit from further clarification or improved participant knowledge.

The scores presented in Table 5 show differences in performance across the multiple mini-games. On average, players scored the highest in Electro's mini-game, then Aqua and finally on Verdis. This disparity suggests differences in the difficulty of the mini-games.

User Study	Mini-game Score		
	Aqua	Electro	Verdis
1	771	2461	121
2	0	1260	600
3	3340	2273	130
4	676	3379	1950
5	1942	4350	1820
6	1053	975	1200
Mean	1297	2449,67	970,17

Table 5: Scores and Mean for Each of the Mini-Games

The score of 0 for the User Study 2 in Aqua's mini-game occurred as the players exceeded the given time to solve the puzzles.

– **Custom Question Analysis**

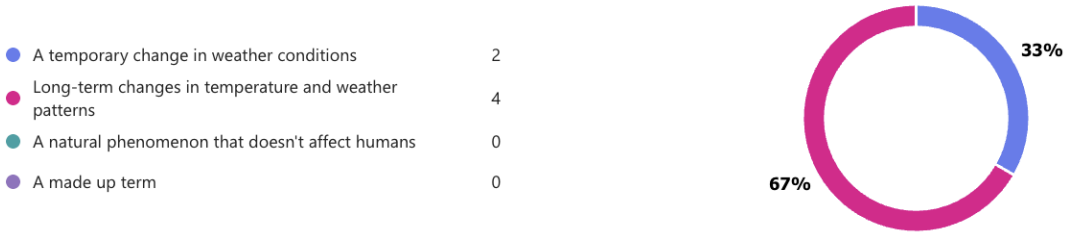


Figure. 55: Results from the Question "What is climate change?" in the Pre-Game Questionnaire

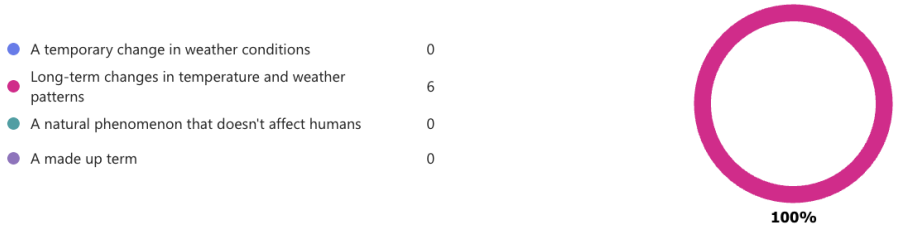


Figure. 56: Results from the Question "What is climate change?" in the Post-Game Questionnaire

The Pre-Game and Post-Game questionnaires contained a single question and a set of questions aimed at evaluating the adult player's views on climate change and sustainability. Fig.55 and Fig.56 show the answers for the question "What is climate change?" obtained before and after the gameplay of *Mystiria*. The correct answer is "Long-term changes in temperature and

weather patterns.". From the results, it is evident that before the game not all players had the correct answer, but after they did.

Regarding the set of questions, Fig.57 and Fig.58 show the pre-game and post-game data respectively.

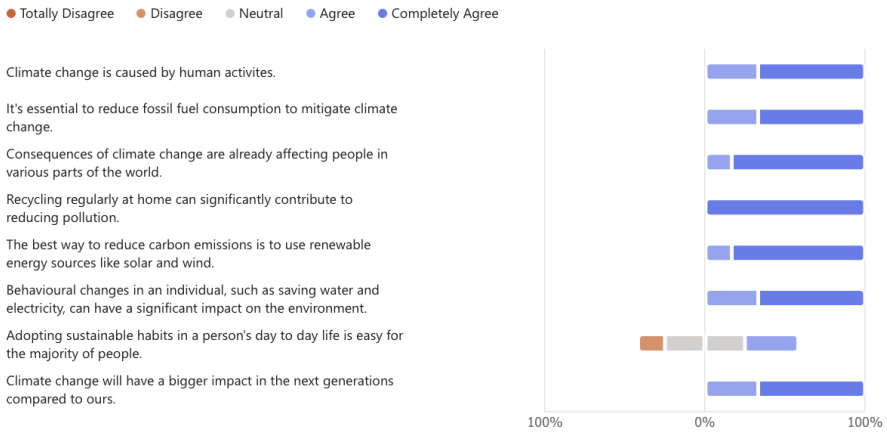


Figure. 57: Results from the Set of Custom Questions in the Pre-Game Questionnaire

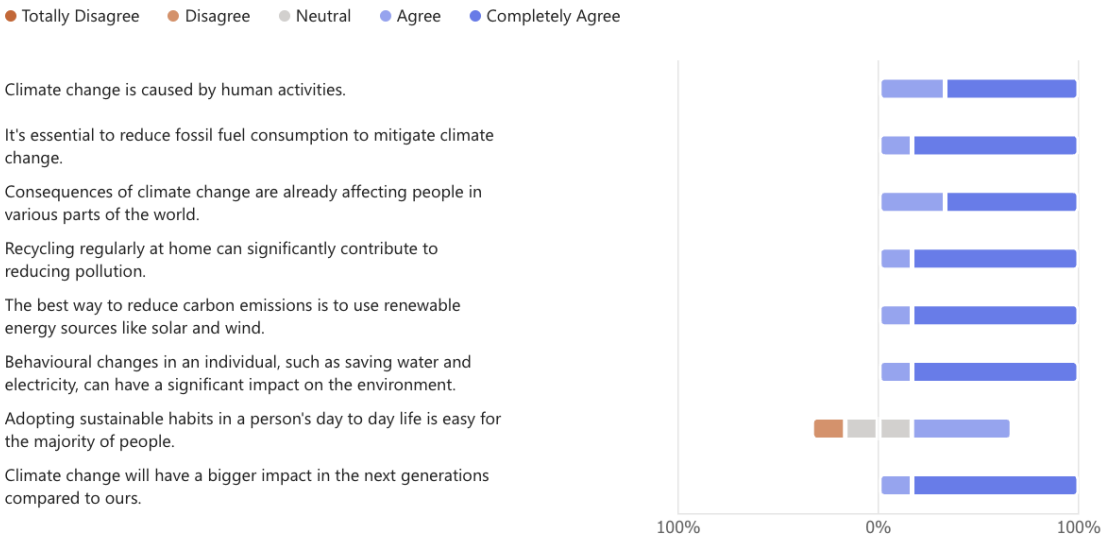


Figure. 58: Results from the Set of Custom Questions in the Post-Game Questionnaire

Post-game there was an increase in agreement with statements like "*It is essential to reduce fossil fuel consumption to mitigate climate change.*" and "*Behavioural changes in an individual, such as saving water and electricity, can have a significant impact on the environment.*". Nonetheless, scepticism from the participants was noted while regarding "*Adopting sustainable*

habits in a person's day to day life is easy for the majority of people.". When responding to this question, 2 adult participants (A1 and A6) expressed concerns with the researcher, mentioning the fact that most of them do not have recycling bins near their house, which makes recycling difficult.

– **Child Questionnaire Analysis**

After completing the game, children filled out a questionnaire specifically designed for younger audiences, using a pictorial Likert scale to ensure accessibility and comprehension. The results, presented in Fig.59, indicate that the game elicited positive feedback from the children. All children reported that they found the game enjoyable and engaging. Additionally, an observation was the children's enthusiasm to play alongside the adults, as, in a 5 point pictorial Likert scale, 66.7% of children selected the highest rating (5) for the statement "I liked playing with the adult".

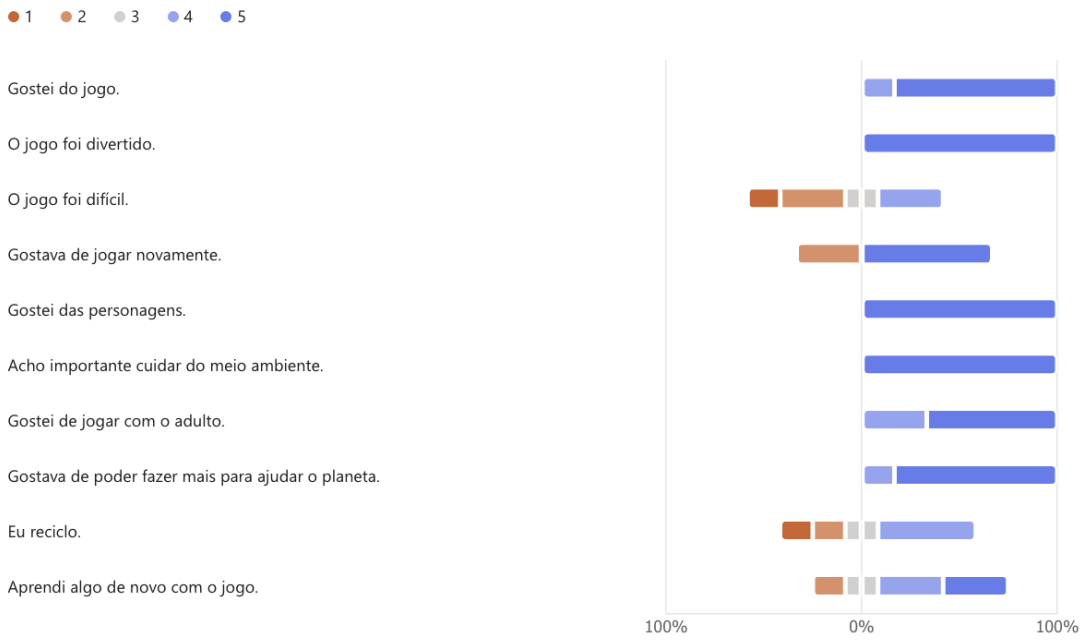


Figure. 59: Results from the Post-Game Child Questionnaire

– **NEP Scale** The NEP scale was used to analyse adult participants' environmental attitudes and awareness before (see Fig.60) and after (see Fig.61) engaging with *Mystiria*. The results were categorized across five dimensions:

- ***Reality of Limits to Growth***: This dimension recognizes that there are ecological constraints on human activity and that population growth is unsustainable (pre-game: M=9.83, SD=2.04; post-game: M=10.67, SD=2.34).
- ***Anti-Anthropocentrism***: This dimension challenges the belief that humans are superior and separate from nature (pre-game: M=14.00, SD=1.26; post-game: M=14.67, SD=0.82).
- ***Fragility of Nature's Balance***: Understanding that natural cycles are delicate and can be disrupted by human actions, leading to serious environmental consequences (pre-game: M=13.33, SD=1.37; post-game: M=13.83, SD=2.04).
- ***Rejection of Exceptionalism***: This dimension opposes the idea that humans are exempt from the natural laws and ecological limits (pre-game: M=11.00, SD=3.16; post-game: M=11.33, SD=3.08).
- ***Possibility of an Eco-crisis***: Accepting that environment degradation poses a significant threat and that urgent action is necessary to avoid ecological disasters (pre-game: M=12.67, SD=1.51; post-game: M=13.83, SD=1.94).

While all five dimensions showed an increase, the most notable change was in the *Possibility of an eco-crisis*.

Summing NEP values for each participant is important as it provides a clear aggregate measure of an individual's environmental attitudes. These values represent the strength of a person's pro-environmental beliefs and their acceptance of ecological principles. A higher total NEP score typically indicates a stronger endorsement of the ecological world-view, suggesting that the individual believes in the importance of environmental preservation. The results portrayed in Fig.62 show a higher total sum increase for participants A2 (66 to 71), A4 (62 to 71) and A5 (57 to 63). A minor improvement was observed in participants A1 (68 to 69) and A3 (63 to 65). On the other hand, participant A6 showed a decline (49-47).

Figure. 60: Results from the NEP scale in the Pre-Game Questionnaire

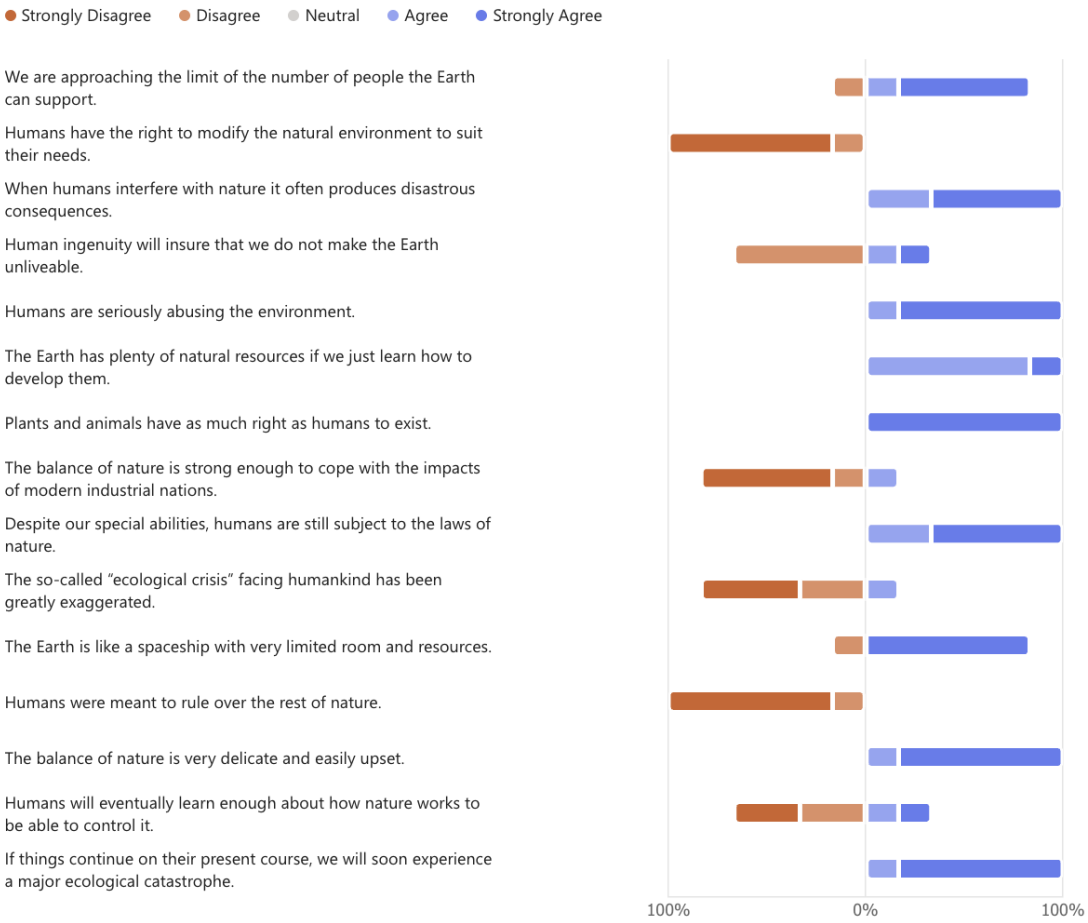


Figure. 61: Results from the NEP scale in the Post-Game Questionnaire

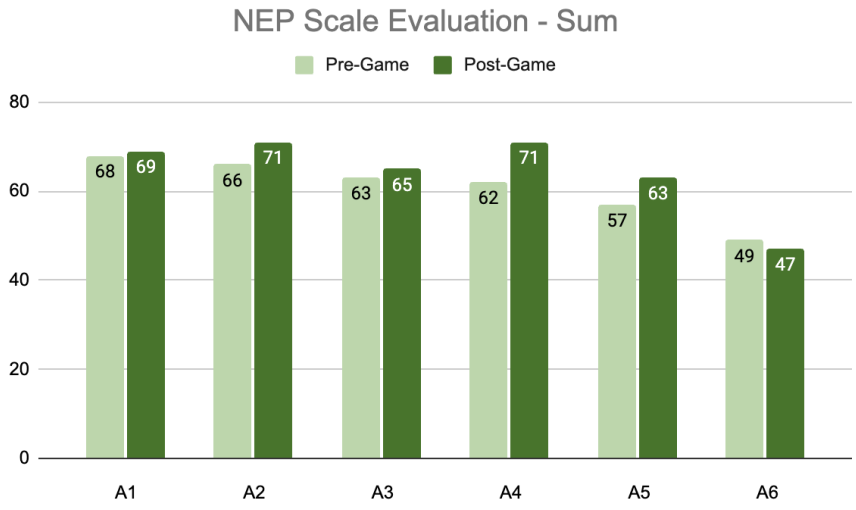


Figure. 62: NEP Scale Sum for Each Adult Participant

– **GEQ scale**

For the GEQ, we used the core and post-game modules to evaluate players' in-game experiences and reflections after gameplay.

Components	Mean	Standard Deviation
Competence	3.167	0.236
Sensory and Imaginative Immersion	3.694	0.340
Flow	2.400	1.038
Tension/Annoyance	0.111	0.192
Challenge	1.333	0.773
Negative affect	0.208	0.417
Positive affect	3.800	0.139

Table 6: GEQ - Core Module Results

Components	Mean	Standard Deviation
Positive experience	3.361	0.371
Negative experience	0.306	0.356
Tiredness	0.000	0.000
Returning to Reality	1.111	1.206

Table 7: GEQ - Post-Game Module Results

The evaluation of the core and post-game modules reveals a positive gameplay experience. The high scores in sensory and imaginative immersion, positive affect and competence indicate a strong engagement and enjoyment by the adult players, with minimal tension/annoyance or negative affect. The post-game data reflects a prevailing positive experience and negligible negative experiences or tiredness. The variability in flow and returning to reality provide opportunities to further refine the game.

7.5 Qualitative Results

– **Semi-structured Interview Analysis**

The following section provides an overview of the thematic analysis of the data collected from the semi-structured interviews. By identifying recurring themes, this analysis will provide insights into how *Mystiria* fosters both education and collaboration between players. This thematic analysis also allowed us to identify any challenges or areas for improvement that can help enhance the educational effectiveness of the game and user experience.

Since the interviews were conducted with both the adult and child, the nomenclature to identify which players we will talk about is, for example, A1 and C1 for the first adult participant and for the first child participant, respectively.

1. **User Engagement and Enjoyment**

   Throughout the interviews, participants expressed high levels of engagement and enjoyment. Their feedback highlighted a positive and immersive experience, with many players referencing specific aspects of the game that contributed to their enjoyment.

   - **Positive Experience**: When players were asked about the overall experience of the game, all of the players had something positive to say: "*It was very good.*" - C1; "*I loved it.*" - C2; "*I am not used to playing, but I think it's a very educational game.*" - A2; "*I liked it a lot. It was very educational but also fun. I also liked the final part where we could see the initiatives done in Madeira Island. And the final photo we took with the characters, it was a fun experience.*" - A3; "*It was great, there was good interaction.*" - A4.

   - **Favourite Mini-Game**: The mini-game that players like the most was Aqua's, with 8 participants preferring this one, then Electro's with 3 and finally Verdis' with 1.

   - **Challenges**: When players were asked what elements they found most challenging, some mentioned Verdis' mini-game: "*Recycling, I found that the most difficult.*" - C2; "*The recycling one was the hardest.*" - C3; "*I found the recycling part the most challenging because the child doesn't yet have a strong sense of how to recycle.*" - A3; "*Um, I think the most challenging thing was the recycling game, when the fires were appearing and we were not able to collect the garbage correctly.*" - A5. One participant found the mini-games in general the most challenging aspect of the game, as they don't play games too often: "..., *the most challenging part is the games because I am not used to them ...*" - A6.

   - **Suggestions for Improvement**: Some players suggested improvements related to the mechanics in the mini-games, such as: "*I would have liked to see the fire that the adult saw in the recycling game.* - C1; "*That the child could have seen the trash bins.*" - A1, but one player suggested that the characters should talk. In their opinion, children could be more engaged with the game as they were listening to an audio, instead of

trying to read or having the adult read to them: "*The characters having a voice. I think it would make it much more fun because it is a game that can be played by many ages. But not everyone can manage, for example, a 6-year-old child can play the game but might not be able to read everything written there. And if it's the character speaking, they would focus more quickly and understand the content.*" - A6. A couple of players also mentioned that no improvements were needed: "*I have nothing to point out, I found it super fun.*" - A4.

2. **Adult-Child Interactions**

The interactions between the adult and child played a crucial role in the gameplay and game experience, specifically in the areas of collaboration and communication.

- **Collaboration**: The need to cooperate with each other in order to be successful was seen as one of the main aspects of the game. All participants noted that collaboration was essential for completing tasks.

- **Communication**: When participants were asked if they needed to communicate with each other, they all said yes: "*Yes. Communication is fundamental.*" - A4; "*Yes, otherwise it would not work.*" - A5; "*Very much so.*" - A6. When asked to give an example, most players mentioned they needed to communicate the most during the mini-games: "*C: In recycling, because it would've difficult to guess the recycling bin. Only if the adult burned the ones that were not right.*" - C5; "*In the water game and also in the questionnaires.*" - A6; "*To solve the mini-games, we needed to talk to each other, but we should have communicated even more. Then we would have overcome the challenges faster.*" - A1. Participants recognized that the collaborative nature of the game led to conversations about strategies and solutions to solve the mini-games, which led to better understanding of the topics mentioned in the game. These conversations also led to knowledge transfer between players, which was evident in comments made during the gameplay. For example, when reading the narrative for Electro's the players were prompted with the following question: "Do you have any idea of what we can use?", after the character talked about other options instead of fossil fuels. To this, their answer was: C1 - "*Real fuels.*" A1 - "*Like what?*" C1 - "*Like electricity created from the sun.*"

- **Complex Topics**: Complex topics refer to subjects that are difficult to understand, communicate or discuss, especially when the audience is a child. These topics often involve abstract or multifaceted concepts that may require deep knowledge or emotional maturity to fully grasp them. These are topics such as climate change, economic concepts, death and loss, mental health, etc. From the conducted interviews, we were able to gather that most adults have a hard time talking to children about these topics at home, especially climate change, except for two participants, that when asked how they did it, their answers were as follows: "*Slowly.*" - A4; "*I try to speak in clear, simple language that they can understand and that is appropriate for their age.*" - A6. However, when players were asked if the game facilitated discussion about these, the response was very positive: "*Yes, it made it easier because, as the topics were given, it was easier to talk about them with the child.*" - A1; " *Yes. I think it's quite educational. It should even be applied in schools because it's a way to encourage children to... Because let's be honest, most people don't recycle, but I think today's children, if they start early to internalize these values and we show them how important it is, they will be able to make a significant difference.*" - A2; "*Definitely, because it presents the topics in a fun way.*" - A3.

3. **Climate Change Awareness**

The game's educational impact was also a significant aspect mentioned by the participants. Both children and adults reflected on the ways the game helped to raise awareness about climate change and sustainability.

- **Educational Impact**: The adult participants reported that the game reinforced their pre-existing knowledge of environmental issues, while also introducing new ideas and strategies for a more sustainable living: "*The game conveyed a lot, very important things. That we humans need to take care of the planet.*" - A1; "*It helped to open my mind more and think that we need to change our habits.*" - A2; "*It refreshed the topics, but of course, as an adult, this is an area that concerns me, and I try to stay updated on the topic.*" - A2; "*My memory was refreshed on things I already knew, but I was also able to learn new things. And I also believe it was an interactive game for both me and the child.*" - A5; "*It reminded us that if everyone contributes, it is a big step*

toward change." - A6. For some children, the game served as a reminder for what they already learned at school: "*It relates to everything. We cover that at school.*" - C4; "*It is basically the same thing, they explain it the same way but without the games.*" - C5; "*I have already learned about that at school.*" - C6, while for other, it introduced new topics: "*The game talked about things I didn't know yet.*" - C3.

- **Main Message from Mini-games**: When players were asked what the main message from Aqua's mini-game is, they focused on water conservation, the importance of maintaining the plumbing systems, how important water is and the need to protect and save it. Regarding Electro's mini-game, players focused on the need to save electricity, to use solar panels, to use more renewable energies instead of fossil fuels: "*And also that renewable energies should be adopted to help the planet and reduce the emission of pollutants.*" - A2. For Verdis' mini-game, players emphasised the importance of proper recycling, how we should not burn trash, that glass does not decompose and how to recycle properly.

- **Real-World Relevance**: Participants often reflected on how the game's content connected to real-world practices. For instance, adults mention that the game made them more conscious of their waste usage and waste management, while children understood the relevance of sustainability in everyday life, such as saving water and reducing energy consumption.

4. **Suitability for Mixed-Aged Players**

   As the game was designed for both adults and children, the semi-structured interview also focused on this aspect. Players reported that they thought the game was appropriate for both children and adults, but also mentioned some improvements: "*Yes, I think so, but with the child's age I played with, I thought she was not very familiar with the topic, especially with the questions. The game seemed appropriate for her age, but some of the questions, the child still didn't have a full understanding of.*" - A2; "*Yes, I thought the communication aspect was very interesting, and the games were easy to understand.*" - A3.

– **Observation Tables**

Observations from the game focused the attention on how talking about these topics at home has a great impact. Two child participants of the same age, that went to the same school had

completely different understandings of the topics present in *Mystiria*. One child was able to understand what was being talked about and had a pretty good notion of the topic, while the other child struggled a lot with the overall sustainability and climate change topics,especially the questions.

8 Discussion

In this discussion, we will focus on the two research questions, presenting the key findings and their implications. Additionally, we reflect on the prototype's strengths and limitations, suggest improvements and outline implications for future educational game design.

8.1 RQ1: What elements of the educational game contribute to user engagement and enjoyment, particularly within the context of climate change awareness?

Findings from the user study indicate that several design elements of *Mystiria* played a crucial role in maintaining user engagement and enhancing enjoyment. The most significant factor was the collaborative and asymmetric nature of the mini-games. Since players had distinct yet interdependent roles, communication was needed for progress, which reinforced engagement for both participants. This aligned with previous research, suggesting that cooperative gameplay increases immersion [2]. However, beyond enhancing the game experience, this asymmetric collaboration also supported climate change awareness by encouraging players to actively explain and reflect on the topics discussed in the game. For example, adults often needed to emphasise to children why water should be conserved or how waste should be sorted, embedding awareness and learning into the collaborative process.

Furthermore, questionnaire responses indicated that children enjoyed playing with the adults, emphasising the appeal and significance of collaborative intergenerational play and how it increases engagement in the game.

Players expressed that the narrative structure of *Mystiria* also contributed to engagement, by providing a meaning and sense of purpose to the actions completed in the gameplay. This positive feedback reinforces the idea that well-integrated narratives increase engagement [41].

8.2 RQ2: How does the interaction between adult and child promote discussion and/or knowledge transfer about climate change awareness?

Observations and user feedback suggest that ACI facilitated meaningful discussion and knowledge transfer during gameplay. The collaborative nature of the game encouraged players to communicate

frequently about climate change, particularly during the quizzes and in the narrative conversation prompts. These in-game discussions revolved around the importance of water conservation, renewable energy and recycling. Adults sometimes guided children in having a better understanding of these topics, reinforcing research on the importance of intergenerational learning in serious games [62, 63].

The results of the custom questions in the pre and post-game questionnaires further suggest that *Mystiria* reinforced learning about climate change concepts. The adult's presence seemed to support the child's learning process. Additionally, the adults also seemed to improve their knowledge, as indicated by higher accuracy in post-game questionnaire responses. This increase suggests the game has the potential as an effective tool for sustainability education, aligning with studies which advocate for game-based learning [46, 47].

The findings indicate that beyond individual learning, *Mystiria* fostered a dynamic in which the adult acted as a facilitator, helping children process and better understand sustainability topics. This supports existing literature on the positive influence adult role models have in increasing engagement and knowledge retention [29].

8.3 *Mystiria's* Impact in understanding of climate change

The analysis of the custom questions before and after gameplay reveals *Mystiria's* effectiveness in enhancing the adult player's understanding of climate change. By engaging with the game, participants were exposed to educational content and interactive tasks that likely reinforced their comprehension of the topics. The shift from incorrect answers before gameplay to fully correct answers afterwards highlights the game's potential as an effective tool for raising awareness about climate change and sustainability. In this regard, *Mystiria* seems to present a mechanism for educating players and encouraging long-term knowledge retention about climate change and sustainable practices.

As previously presented, the NEP scale results increased in all of the five dimensions. The increase in the *Reality of Limits to Growth* dimension indicates a heightened awareness of the finite nature of resources. This might suggest the game reinforced the concept of ecological limitations. A slight increase in the *Anti-Anthropocentrism* dimension could reflect a shift toward recognizing the value of nature independent of its utility to humans. An improvement of the *Fragility of Nature's*

Balance dimension can indicate that participants can better appreciate the delicate balance of natural ecosystems. A marginal rise in the *Rejection of Exceptionalism* dimension suggests a slight shift in rejecting the notion that humans are superior to nature. The *Possibility of an Eco-crisis* showed the highest increase, suggesting that the game was particularly effective in emphasising the urgency of climate change. These improvements suggest that *Mystiria* reinforced key ecological concepts and contributed to raising awareness on climate change.

The GEQ results further support the effectiveness of *Mystiria*, with the high scores for immersion (*Sensory and Imaginative Immersion*) and enjoyment (*Positive Experience*). Negative emotions were minimal (*Negative Experience*), which suggests that the game was able to successfully balance challenge and accessibility. The scores obtained reinforce that *Mystiria* provides a solid foundation for future iterations.

All children reported finding the game enjoyable and engaging, indicating the design's success in catering to their needs. In the child's questionnaire, when asked if the game was fun, 100% of children agreed, underlining the significant impact of the game's mechanics in contributing for enjoyment and engagement. Children also expressed a strong affinity to the game's characters, which likely contributed to an emotional engagement and immersion in the narrative. Additionally, an observation was the children's enthusiasm for playing alongside an adult. On 5 point pictorial Likert scale, 66.7% of children selected the highest rating (5) for the statement "I liked playing with the adult", highlighting the appeal and importance of collaborative intergenerational play. This reinforces the idea that playing with an adult enhanced both enjoyment and engagement, possibly due to the supportive aspects of co-play.

Nonetheless, some areas still need improvement to enhance the overall experience and intergenerational knowledge transfer. One notable challenge was the difficulty of Verdis' mini-game, which disrupted the game flow. Additionally, during the quizzes, some participants would answer quickly without engaging in deeper discussions, limiting possible knowledge transfer between the adult and child. Another potential improvement is adding audio for the characters, as mention by A6 - " *The characters having a voice. I think it would make it much more fun because it's a game that can be played by many ages. But not everyone can manage, for example, a 6-year-old child can play the game but might not be able to read everything written there. And if it's the character speaking,*

they would focus more quickly and understand the content.". This could possibly increase child's engagement with the game and capture their attention more effectively.

Overall, *Mystiria* has potential for use in a school environment, provided the teacher or adult playing with the child is aware of the importance of communication.

8.4 Implications for Game Design in Educational Games

The findings from this study could have broader implications and could possibly be applied to other similar games:

- **Asymmetric Cooperative Play and Intergenerational Learning**: The use of interdependent roles fostered teamwork, engagement and communication. This design encouraged discussions between the adult and child, reinforcing problem-solving skills, joint decision-making and knowledge transfer. Additionally, it can leverage the importance of adult role models to enhance the learning experience. Future educational games can benefit from implementing similar mechanics, where players have unique but complementary tasks, promoting both cognitive and social learning.
- **Narrative-Driven Learning**: Creating a good storyline can enhance player immersion and motivation, which reinforces the importance of a well-designed narrative. In *Mystiria*, the inclusion of local context narrative appeared to strengthen player's connection to the game, making the learning experience more impactful. This localized approach may have contributed to knowledge retention, highlighting the potential of local-context based narratives as an effective strategy for educational games.
- **Designing of a Game for Adults and Children**: In the user study of *Mystiria* and in the observations taken during the game, both adult and child players praised the characters and the visuals of the game, despite the design being primarily focused on children. This highlights how well-design UI elements can appeal to broader audiences, possibly enhancing the overall game experience. Furthermore, it suggests that AI-generated characters, when thoughtfully implemented, can enhance the overall game experience by creating visually engaging aesthetics for diverse players.
- **Accessibility**: Games that provide multiple modes of interaction (e.g. text and audio) can be more appealing to diverse audiences, by ensuring the educational content is accessible to all.

8.5 Limitations and Future Work

Despite its success, the study faced certain limitations. The small sample limits the generalizability of our findings, and participants played the game only once, making it difficult to evaluate long-term knowledge retention. Future studies should consider larger sample sizes and longitudinal studies to evaluate the game's sustained impact on players over time.

While the game successfully fostered collaboration between players, some tasks were more challenging, particularly Verdis' mini-game. This suggest the need for further refinement of its mechanics to improve the gameplay experience and overall player satisfaction. Verdis' consistently lower scores potentially point to difficulties in the child knowing what to put in each of the recycling bins or the adult not communicating well with the child. This may indicate a gap in the gameplay mechanics that hinder a smooth gameplay experience. Addressing these challenges could improve this mini-game, contributing for a better experience.

Another limitation is in the semi-structured interviews, as the questions may have constrained the depth of participant responses. Future studies should refine these questions to capture more detailed insights into player experiences, learning outcomes, discussions at home about sustainability topics, and, if these discussions do not occur, the reasons behind it. By exploring why some participants do not engage in such discussions could provide deeper insights into the potential barriers to knowledge transfer and offer new strategies to facilitate these conversations through games.

Furthermore, as *Mystiria* was designed with a specific local context - Madeira Island - the findings cannot be generalized and the game may not make sense to play in different areas of the world. To address this, future iterations of the game could consider having multiple versions, depending on the geographical location the game would be played in.

9 Conclusion

In this dissertation, we followed the design, development and impact of *Mystiria*, a collaborative intergenerational game aimed at raising awareness of climate change and sustainability.

The results from our user study suggest that Mystiria successfully engaged players in climate change awareness through its cooperative mechanics, narrative and asymmetric play. The study has demonstrated that the game fostered intergenerational knowledge transfer and facilitated meaningful discussions, reinforcing the potential of serious games as tools for sustainability education [46, 47]. However, the game would benefit from refinements in tasks complexity (Verdis' mini-game) and accessibility to more regions in the world to further enhance its impact.

Ultimately, *Mystiria* presents a compelling model for future educational games in intergenerational contexts, that not only entertain but also educate and inspire action towards a more sustainable future. The game's ability to blend asymmetric gameplay mechanics, interactive storytelling, narrative prompted discussions and quizzes in a collaborative environment, further supports previous literature that serious games can play a pivotal role in shaping the next generation of environmentally conscious citizens.

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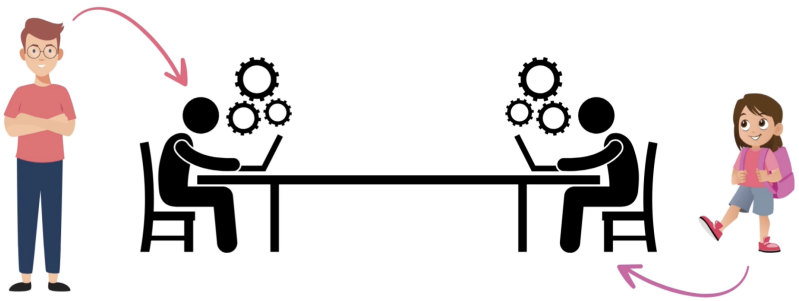
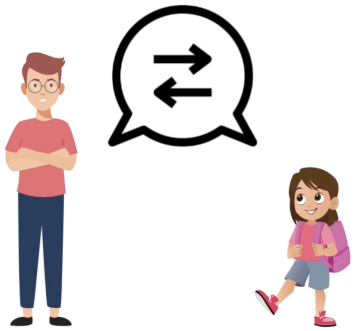
A Appendix: Game Tutorial

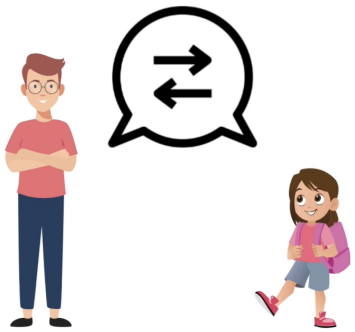
In this section, the game tutorial presented to players before the game begins will be presented. The shown version is in English but there also is a Portuguese version. Each of the tutorials has a narrator to guide players. The goal of this tutorial is to emphasize the need for players to communicate during the game in order to succeed, as they won't be able to see each other's screen.



You'll be working together but there's a challenge: you can only see your screen and you can't see the other player's!



You'll need to talk to each other, share what's happening and listen carefully to your partner.



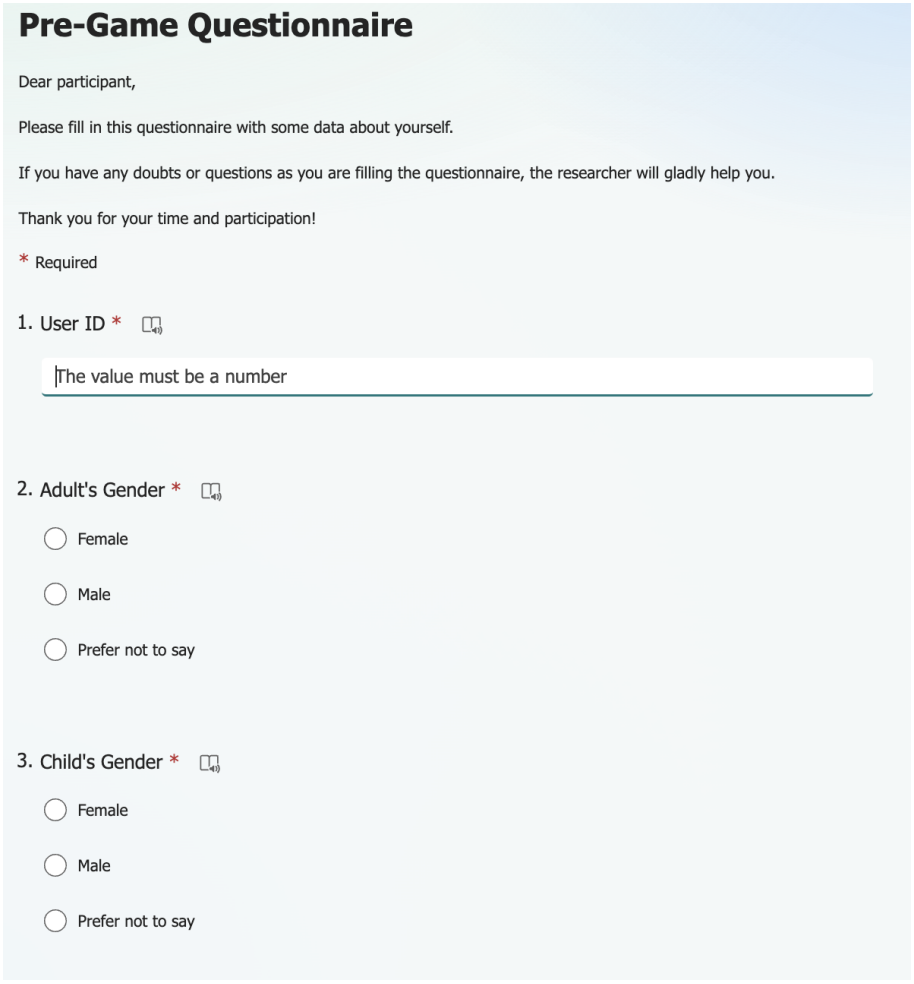
By describing what you see and discussing your ideas, you can discover the clues and complete the tasks together.

Remember, good communication is the key to success!

B Appendix: Quiz Questions

Character	Question	Answer 1	Answer 2	Answer 3	Answer 4	Correct Answer
Aqua	How does climate change affect water?	It makes rainbows more colourful	It makes ice caps melt faster reducing our fresh water	It helps flowers grow bigger	It makes rivers flow faster	2
	How does climate change impact the water cycle?	Accelerates the water cycle	Decreases rainfall everywhere	Increases the frequency of extreme weather events	Climate change has no effect on the water cycle	3
	What can we do to help with water problems caused by climate change?	Play outside with water	Throw thrash in the water	Use more water for fun activities	Use less water overall	4
Electro	How do renewable energy sources impact air pollution?	Increase pollution	Does not have any impact	Produce electricity without emitting harmful pollutants	Only benefits specific industries	3
	How do renewable energy sources combat climate change?	By increasing greenhouse gas emissions	No impact on climate change	By reducing reliance on fossil fuels	By increasing reliance on coal	3
	How can individuals support renewable energy transition?	Increase energy consumption from fossil fuels	Conserve energy and use energy-efficient appliances	There is nothing you can do	Purchase energy from coal-fired power plants	2
Verdis	Is it necessary to wash packaging before returning it to the yellow recycling bin?	Yes	No	-	-	2
	How does recycling contribute to mitigating climate change?	Reduces greenhouse gas emissions	No impact	Increases emissions due to the energy needed for processing	Only benefits local economies and has no global impact	1
	Why is proper sorting of recyclables important?	It is not important	Only benefits local economies and has no global impact	Generates more waste	Ensures effective recycling and prevents contamination	4

C Appendix: Questionnaires



Pre-Game Questionnaire

Dear participant,

Please fill in this questionnaire with some data about yourself.

If you have any doubts or questions as you are filling the questionnaire, the researcher will gladly help you.

Thank you for your time and participation!

* Required

1. User ID *

The value must be a number

2. Adult's Gender *

- Female
- Male
- Prefer not to say

3. Child's Gender *

- Female
- Male
- Prefer not to say

4. Adult's Age *

The value must be a number

5. Child's Age *

The value must be a number

6. What types of games do you and your children play? Please select all that apply. *

- [ ] Video games
- [ ] Board games
- [ ] Card games
- [ ] Outdoor/Playground Games
- [ ] Puzzles

Understanding Climate Change

7. What is climate change? *

- ( ) A temporary change in weather conditions
- ( ) Long-term changes in temperature and weather patterns
- ( ) A natural phenomenon that doesn't affect humans
- ( ) A made up term

8. Please read the following statements and for each, chose the option you best identify with. *

	Totally Disagree	Disagree	Neutral	Agree	Completely Agree
Climate change is caused by human activites.	◯	◯	◯	◯	◯
It's essential to reduce fossil fuel consumption to mitigate climate change.	◯	◯	◯	◯	◯
Consequences of climate change are already affecting people in various parts of the world.	◯	◯	◯	◯	◯
Recycling regularly at home can significantly contribute to reducing pollution.	◯	◯	◯	◯	◯
The best way to reduce carbon emissions is to use renewable energy sources like solar and wind.	◯	◯	◯	◯	◯
Behavioural changes in an individual, such as saving water and electricity, can have a significant impact on the environment.	◯	◯	◯	◯	◯
Adopting sustainable habits in a person's day to day life is easy for the majority of people.	◯	◯	◯	◯	◯
Climate change will have a bigger impact in the next generations compared to ours.	◯	◯	◯	◯	◯

NEP scale

9. For each statement, please select the option that best reflects your views. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
We are approaching the limit of the number of people the Earth can support.	◯	◯	◯	◯	◯
Humans have the right to modify the natural environment to suit their needs.	◯	◯	◯	◯	◯
When humans interfere with nature it often produces disastrous consequences.	◯	◯	◯	◯	◯
Human ingenuity will insure that we do not make the Earth unliveable.	◯	◯	◯	◯	◯
Humans are seriously abusing the environment.	◯	◯	◯	◯	◯
The Earth has plenty of natural resources if we just learn how to develop them.	◯	◯	◯	◯	◯
Plants and animals have as much right as humans to exist.	◯	◯	◯	◯	◯
The balance of nature is strong enough to cope with the impacts of modern industrial nations.	◯	◯	◯	◯	◯
Despite our special abilities, humans are still subject to the laws of nature.	◯	◯	◯	◯	◯
The so-called "ecological crisis" facing humankind has been greatly exaggerated.	◯	◯	◯	◯	◯
The Earth is like a spaceship with very limited room and resources.	◯	◯	◯	◯	◯
Humans were meant to rule over the rest of nature.	◯	◯	◯	◯	◯
The balance of nature is very delicate and easily upset.	◯	◯	◯	◯	◯
Humans will eventually learn enough about how nature works to be able to control it.	◯	◯	◯	◯	◯
If things continue on their present course, we will soon experience a major ecological catastrophe.	◯	◯	◯	◯	◯

Post-Game Questionnaire

Dear participant,

Please fill in this questionnaire with some data about yourself.

If you have any doubts or questions as you are filling the questionnaire, the researcher will gladly help you.

Thank you for your time and participation!

* Required

1. User ID *

The value must be a number

Understanding Climate Change

2. What is climate change? *

- ◯ A temporary change in weather conditions
- ◯ Long-term changes in temperature and weather patterns
- ◯ A natural phenomenon that doesn't affect humans
- ◯ A made up term

3. Please read the following statements and for each, chose the option you best identify with. *

	Totally Disagree	Disagree	Neutral	Agree	Completely Agree
Climate change is caused by human activites.	◯	◯	◯	◯	◯
It's essential to reduce fossil fuel consumption to mitigate climate change.	◯	◯	◯	◯	◯
Consequences of climate change are already affecting people in various parts of the world.	◯	◯	◯	◯	◯
Recycling regularly at home can significantly contribute to reducing pollution.	◯	◯	◯	◯	◯
The best way to reduce carbon emissions is to use renewable energy sources like solar and wind.	◯	◯	◯	◯	◯
Behavioural changes in an individual, such as saving water and electricity, can have a significant impact on the environment.	◯	◯	◯	◯	◯
Adopting sustainable habits in a person's day to day life is easy for the majority of people.	◯	◯	◯	◯	◯
Climate change will have a bigger impact in the next generations compared to ours.	◯	◯	◯	◯	◯

NEP scale

4. For each statement, please select the option that best reflects your views. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
We are approaching the limit of the number of people the Earth can support.	○	○	○	○	○
Humans have the right to modify the natural environment to suit their needs.	○	○	○	○	○
When humans interfere with nature it often produces disastrous consequences.	○	○	○	○	○
Human ingenuity will insure that we do not make the Earth unliveable.	○	○	○	○	○
Humans are seriously abusing the environment.	○	○	○	○	○
The Earth has plenty of natural resources if we just learn how to develop them.	○	○	○	○	○
Plants and animals have as much right as humans to exist.	○	○	○	○	○
The balance of nature is strong enough to cope with the impacts of modern industrial nations.	○	○	○	○	○
Despite our special abilities, humans are still subject to the laws of nature.	○	○	○	○	○
The so-called "ecological crisis" facing humankind has been greatly exaggerated.	○	○	○	○	○
The Earth is like a spaceship with very limited room and resources.	○	○	○	○	○
Humans were meant to rule over the rest of nature.	○	○	○	○	○
The balance of nature is very delicate and easily upset.	○	○	○	○	○
Humans will eventually learn enough about how nature works to be able to control it.	○	○	○	○	○
If things continue on their present course, we will soon experience a major ecological catastrophe.	○	○	○	○	○

Game Experience Questionnaire - Core Module

5. Please indicate how you felt while playing the game for each of the items, on the following scale. *

	Not at all	Slightly	Moderately	Fairly	Extremely
I felt content	◯	◯	◯	◯	◯
I felt skilful	◯	◯	◯	◯	◯
I was interested in the game's story	◯	◯	◯	◯	◯
I thought it was fun	◯	◯	◯	◯	◯
I was fully occupied with the game	◯	◯	◯	◯	◯
I felt happy	◯	◯	◯	◯	◯
It gave me a bad mood	◯	◯	◯	◯	◯
I thought about other things	◯	◯	◯	◯	◯
I found it tiresome	◯	◯	◯	◯	◯
I felt competent	◯	◯	◯	◯	◯
I thought it was hard	◯	◯	◯	◯	◯
It was aesthetically pleasing	◯	◯	◯	◯	◯
I forgot everything around me	◯	◯	◯	◯	◯
I felt good	◯	◯	◯	◯	◯
I was good at it	◯	◯	◯	◯	◯
I felt bored	◯	◯	◯	◯	◯
I felt successful	◯	◯	◯	◯	◯
I felt imaginative	◯	◯	◯	◯	◯
I felt that I could explore things	◯	◯	◯	◯	◯
I enjoyed it	◯	◯	◯	◯	◯

6. Please indicate how you felt while playing the game for each of the items, on the following scale. *

	Not at all	Slightly	Moderately	Fairly	Extremely
I was fast at reaching the game's targets	◯	◯	◯	◯	◯
I felt annoyed	◯	◯	◯	◯	◯
I felt pressured	◯	◯	◯	◯	◯
I felt irritable	◯	◯	◯	◯	◯
I lost track of time	◯	◯	◯	◯	◯
I felt challenged	◯	◯	◯	◯	◯
I found it impressive	◯	◯	◯	◯	◯
I was deeply concentrated in the game	◯	◯	◯	◯	◯
I felt frustrated	◯	◯	◯	◯	◯
It felt like a rich experience	◯	◯	◯	◯	◯
I lost connection with the outside world	◯	◯	◯	◯	◯
I felt time pressure	◯	◯	◯	◯	◯
I had to put a lot of effort into it	◯	◯	◯	◯	◯

Game Experience Questionnaire - Post Game Module

7. Please indicate how you felt while playing the game for each of the items, on the following scale. *

	Not al all	Slightly	Moderately	Fairly	Extremely
I felt revived	◯	◯	◯	◯	◯
I felt bad	◯	◯	◯	◯	◯
I found it hard to get back to reality	◯	◯	◯	◯	◯
I felt guilty	◯	◯	◯	◯	◯
It felt like a victory	◯	◯	◯	◯	◯
I found it a waste of time	◯	◯	◯	◯	◯
I felt energised	◯	◯	◯	◯	◯
I felt satisfied	◯	◯	◯	◯	◯
I felt disoriented	◯	◯	◯	◯	◯
I felt exhausted	◯	◯	◯	◯	◯
I felt that I could have done more useful things	◯	◯	◯	◯	◯
I felt powerful	◯	◯	◯	◯	◯
I felt weary	◯	◯	◯	◯	◯
I felt regret	◯	◯	◯	◯	◯
I felt ashamed	◯	◯	◯	◯	◯
I felt proud	◯	◯	◯	◯	◯
I had a sense that I had returned from a journey	◯	◯	◯	◯	◯

D Appendix: Semi-structured Interview

Game in general

1) How do you evaluate the overall experience of the game?
2) Which parts did you enjoy the most or find the most challenging?
3) Which of the mini games or tasks did you find the most interesting?
4) What improvements do you suggest for the game?
5) **For the adult** - Do you think the game was suitable for both adults and children?

Communication

6) Did you feel you were able to work well together?
    a) Did you have to talk to each other to be successful?
        i) Can you give an example?
7) **For the adult** - At home, how do you talk to your child about more complicated topics?
    a) Do you think this game facilitated communication on the topic?
8) **For the adult** - Did you feel the need to explain any of the concepts related to sustainability/climate change to the child?
    a) If yes, can you give an example?
        i) So do you feel like this game was a good tool to explore the topics of climate change and sustainability?
9) **For the child** - How does the game relate to what you learn at school or at home?

Topics covered

10) What topics related to sustainability were covered in the game?
11) What's the main message of Aqua's minigame?
12) What's the main message of Electro's minigame?
13) What's the main message of Verdis' minigame?
14) Did the game help you learn anything new related to climate change and/or sustainability?

E Appendix: Observation Tables

The observation IDs are:

- IRL: In real life examples
- GP: Gameplay
- Q: Quiz
- ACI: Adult-child interactions
- C: Comments made throughout the game

Participant		Observation ID	Observation
Adult	**Child**		
	X	GP	The child began reading the narratives.
X	X	GP	The adult was able to solve the puzzles and could tell where the child was, and where he had to go after.
X	X	GP	Managed to solve all the puzzles but took almost all of the time up, as the adult wasn't used to a computer or to playing games.
	X	GP	In the sunshine saver mini-game, the child was having a bit of difficulty moving the solar panel with the cursor, as they would sometimes press outside the game window.
	X	Q	Child lost interest on the second quiz as the adult was answering alone and not communicating too much with the child.
	X	GP	The recycling game was very complicated for the child as he didn't know how to sort the trash correctly.
X		IRL	Mentioned that they should ask to put the recycling bins outside her house, instead of the common one.
X	X	C	Appreciated the communication factor in the game and were able to communicate well in the mini-games.
X	X	ACI	When reading the narrative the players were prompted with the following question: "Now that you've seen how the water is used on the island, what are some of the best ways to use it?". To this, their answer was: – C: "Drink the water. – A: "How can we protect water?" – C: "Placing it in nice places without trash."
	X	Q	On the third aqua quiz the child read the answers aloud and was saying "No" to the incorrect answers. He was able to quickly identify the correct answer and ask the adult to choose the correct option.
X	X	ACI	When reading the narrative for Electro the players were prompted with the following question: "Do you have any idea of what we can use?", after the character talked about other options instead of fossil fuels. To this, their answer was: – C: "Real fuels." – A: "Like what?" – C: "Like electricity created from the sun."

Participant		Observation ID	Observation
Adult	**Child**		
	X	GP	Noticed straight away that both players were seeing different scenes, as the icon on the top was greyed out.
X	X	ACI	The child was explaining what she was seeing on her screen and the adult did the same. They came to the conclusion that the child was seeing a shining "star", so the child pressed it.
X		GP	Was having a hard time completing the puzzles as they aren't used to playing games.
	X	C	"I know this game!" - Aqua: Connecting the pipes.
	X	ACI	Was explaining the logic of the game to the adult.
X	X	Q	On the aqua quiz, question number 3, the adult asked the child what was the correct answer to which they promptly answered number 4 - which was correct.
	X	C	Kept making comments on how cute the characters were and how much they liked it.
X		GP	Thought that the only enemy was the clouds - Sunshine Savers.
	X	GP	Thought it was too slow - Sunshine Savers.
X	X	ACI	On Electro's quiz both players were communicating and the child knew some of the answers without the help of the adult.
	X	C	"1 star?! I want 3 stars!"
X	X	ACI	Verdis' narrative communication prompt ("Do you know how long it takes for glass to decompose") created the following interaction: – A: "Many years! 50 or more." – C: "1000 years!"
X	X	ACI	When the recycling bin imaged popped up, the adult took this opportunity to remind the child which type of trash went into each of the bins.
	X	GP	Didn't really know where to put the trash.
X	X	GP	Enjoyed exploring the initiatives regarding renewable energy sources in Madeira Island and also taking the final picture.

Participant		Observation ID	Observation
Adult	**Child**		
X		GP	Had some difficulties when solving Aqua's mini-game as they aren't used to playing games.
X	X	ACI	Adult explained to the child what climate change and water cycle are.
X	X	ACI	Explained to the child that they were trying to send the sun without hitting obstacles to be able to take advantage of all of the solar energy.
X	X	GP	Were able to complete the solar panel mini-game section very well.
X	X	ACI	On the Electro narrative interaction prompt, the following interaction happened: – A: "What can we use as natural energy?" – C: "The sun."
	X	C	Wasn't too knowledgeable about some of the game's topics such as climate change and the water cycle. But knew what type of trash to place in each of the recycling bins.
X	X	ACI	Used the narrative interaction prompts and discussed the questions.

Participant		Observation ID	Observation
Adult	**Child**		
	X	GP	Pressed the "shining star" in the forest scene straight away.
X		GP	Read the narrative.
X		C	Compared to other adults, was able to play the mini-games a bit easier because they were more used to this type of interaction.
X	X	C	Were more knowledgeable about the topics mentioned in the game.
X	X	Q	Discussed each of the questions and were able to come to a conclusion together.
X		C	"I think this character is so cute!! - Electro
X	X	C	Enjoyed exploring the initiatives taking place on Madeira Island and the final picture.

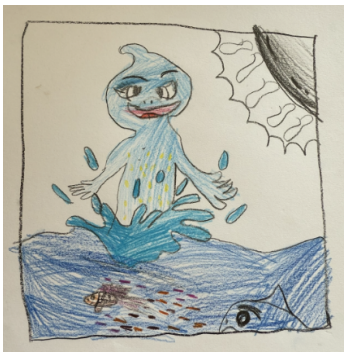
Participant		Observation ID	Observation
Adult	**Child**		
	X	GP	Promptly pressed on the shining star.
	X	GP	Read the narrative.
X	X	ACI	Communicated very well throughout the whole game.
X	X	GP	Were able to solve the puzzles and communicated well throughout the levels.
X	X	ACI	Communicated to solve all of the quiz questions.
	X	C	Was interested in reading the explanation after every one of the questions in the quizzes.
X		GP	On the explanation of Aqua's first question - "Oh wow, that's interesting!"
X	X	C	Were able to understand the mechanics of each game as they were more familiarized with games.
X		ACI	In Electro's Sunshine Savers mini-game, the adult communicated with the child where each of the suns they were spawning were going.
X	X	ACI	On Electro's narrative: – A: " Do you know what fossil fuels are?" – C: "Petroleum."
X	X	ACI	Used the narrative interaction prompts from Electro's
X		C	After Electro's mini-game tutorial. – A: "This is fun, I hadn't thought about this. It's a good idea."
X		C	"Very cute!" - when talking about Verdis.
X	X	C	Communicated very well throughout all of the game.
X	X	ACI	Verdis' talking prompt: – A: "Do you know how many years? I actually don't know." – C: "Some years." – (after explanation) – A: "I had no clue, that's very interesting."
	X	C	Already knew which types of trash went into each of the recycling bins.
	X	C	– C: "The 'mystery' trash can shouldn't be black because black is general waste.
	X	C	– C: "At school they also teach us that recycling avoids the need to produce as many new materials."
	X	C	Didn't know that Madeira Island had the storage dam in Pico da Urze.

Participant		Observation ID	Observation
Adult	**Child**		
X	X	ACI	Communicated well in the first scene and the child clicked promptly on the shining star.
X		C	Understood what the icons on the top right meant and knew whether both players were seeing the same thing or not.
X	X	GP	Communicated well throughout Aqua's levels.
	X	C	– A: "Ah she is so cute!" (Aqua)
X	X	ACI	Both talked in the quiz questions to be able to pick the correct answers.
X		ACI	Emphasized taking shorter showers to the child.
X		C	A: "Oh so cute!" (Electro).
X	X	ACI	– A: "Do you know what fossil fuels are?" – C: "Gasoline and others."
	X	GP	Read Electro's narrative.
X	X	GP	Played the first phase of Electro's mini-game well and the adult was communicating where the suns were going.
X	X	ACI	– C: "I'll clean the clouds." – A: "There's already more light on my screen."
X		C	Wasn't able to place the solar panels on the light spots because they were only clicking instead of dragging as well.
	X	C	Was very knowledgeable in answering the questions. The adult also knew the answers, but was only waiting for the child's answer.
X		C	– A:" Oh look at Verdis, he is very cute as well."
	X	GP	Read Verdis' gameplay.
X	X	ACI	Used Verdis' talking points. – Verdis: Do you know how long it takes for glass to decompose? – A: "Do you know?" – C: "1 year." – A: "No." – Verdis: (explanation) – C: "Since when doesn't glass decompose?" – A: "Since always. At high temperatures it melts but it's always there."
X	X	ACI	Revised what type of waste goes into each of the recycling bins. The adult asked what each type of waste went into the different recycling bins and the child answered correctly.
X	X	ACI	During Verdis' first question, when the players were asked whether to wash packaging, the adult asked about oil bottles and the child answered that they go into the orange recycling bin (Oleão).
X	X	ACI	Were exploring the initiatives on Madeira island well and the adult was asking the child what was the name of the different renewable energies.
X		C	Mentioned they couldn't recycle at their house because they didn't have any recycling bins nearby.

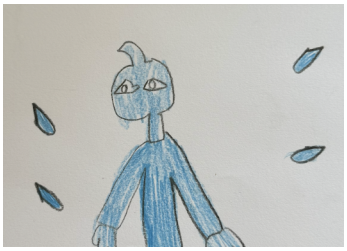
F Appendix: Child Drawings

As mentioned in the user study protocol, the children who participated drew their favourite character from Mystiria.

(a) Drawing by C1



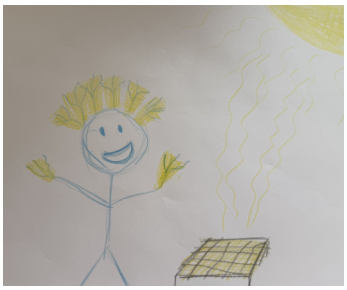
(b) Drawing by C2



(c) Drawing by C3

(d) Drawing by C4

(e) Drawing by C5



(f) Drawing by C6