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Transforming children's knowledge and perception of sharks through a serious game

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Abstract

Due to the alarming decline in shark populations caused by overfishing and unsustainable practices, raising public awareness about this environmental crisis has become crucial. In response, an educational game was developed with the goal of shifting children's negative perceptions of sharks. The game includes two mini-games designed to educate young players about the important role sharks play in maintaining marine ecosystem health. Through interactive activities, the game helps children understand the challenges sharks face as a result of human impact. The mini-games were created to be both educational and engaging, using adaptive mechanisms to tailor the experience to the unique characteristics of each player. This adaptive design allowed for an analysis of how different player profiles interacted with the game, assessing whether the data collected revealed consistent patterns or notable differences across profiles. The developed game contributes to the field of educational games aimed at conservation by encouraging positive attitude shifts towards sharks. Tests conducted with 38 children, aged 9 to 11, revealed a significant increase in their knowledge about sharks and a more positive perception of these animals as a result of playing the game. Furthermore, the game successfully adapted to different player profiles, enabling all participants, regardless of age, gender, or skill level, to intuitively complete the tasks. The study underscores the potential of educational games to inspire more responsible and sustainable behaviors in ocean conservation.

Keywords Serious games · Player profiles · Shark conservation · Perception change · Children's perception of sharks

Extended author information available on the last page of the article

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Introduction

Sharks, as apex predators, play an indispensable role in maintaining the health of marine ecosystems globally with more than 500 different species. Their ability to thrive in a wide range of environments across the world's oceans, from warm tropical waters to cold polar regions, and from deep-sea areas to shallow coastal zones, depicts their significance in regulating marine populations by preying on weak and sick individuals all over the globe (Carrier, Simpfendorfer, Heithaus, and Yopak, 2022; Ebert, Fowler, and Compagno, 2013).

A comprehensive understanding of shark conservation requires considering ecological, economic, and social dimensions. Sharks have existed for over 400 million years, surviving multiple mass extinction events due to their adaptability and the crucial role they play in marine ecosystems (Heithaus, Frid, Wirsing, and Worm, 2008).

Ecologically, sharks play a crucial role in maintaining the balance of marine ecosystems. Their absence can trigger uncontrollable population growth of prey species, which in turn overconsume organisms that feed on plankton. This chain reaction can lead to overgrazing of seagrass beds and coral reefs, causing the degradation of these vital habitats (Heithaus, Frid, Wirsing, and Worm, 2008).

Economically, sharks contribute to various industries, including fishing and tourism. Shark ecotourism has become a significant industry in many regions, where live sharks are valued more than dead ones. For example, shark tourism in the Bahamas has created jobs and generated substantial revenue (Huveneers et al., 2017). However, economic incentives for shark fishing, especially for fins, liver oil, and meat, continue to drive overexploitation. Despite international efforts to regulate and reduce shark finning, demand for shark fins, primarily for shark fin soup, remains a significant threat (Clarke, Magnussen, Abercrombie, McAllister, and Shivji, 2006).

Socially, cultural narratives and media portrayals have shaped the public's perception of sharks. Often depicted as dangerous predators in films like *Jaws* and sensationalized media reports, this negative image influences public attitudes and complicates efforts to garner support for shark conservation. Education and awareness campaigns are critical to shift public perception and to highlight the ecological importance and plight of sharks (Shiffman & Hammerschlag, 2016).

The legal and policy context is also crucial in shark conservation. International agreements, such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), have listed several shark species in order to regulate their trade and ensure sustainability. Regional fisheries management organizations (RFMOs) and national governments have implemented measures, such as fishing quotas, Marine Protected Areas (MPAs), and bans on shark finning. However, enforcement remains a challenge due to the high value of shark products and the often illegal nature of the trade (Dulvy et al., 2014).

Additionally, habitat destruction aggravates these threats. Coastal development, pollution, and climate change are degrading critical shark habitats like coral reefs, reducing their quality and availability. Sharks also fall victim to bycatch, i.e, accidental capture in fishing nets intended for other species, further threatening their survival. These combined pressures have pushed many shark species toward extinction, highlighting the urgent need for comprehensive conservation efforts (Cardeñosa et al., 2022; Topelko & Dearden, 2005).

Given sharks' crucial role in marine ecosystems, their extinction could have severe and far-reaching effects on multiple environments (Shiffman, 2022) as mentioned before. Engaging children in learning about these challenges is part of the solution. Innovative educational strategies are essential for raising awareness and promoting conservation actions.

Portugal, along with Spain, France, and the UK, holds a significant role in European chondrichthyan (shark and rays) fisheries, contributing to the top 20 shark-catching nations worldwide. In 2020, Portugal was ranked 2nd among European Union nations for shark fin import, which demonstrates its high involvement in shark fisheries (Shea, Slee, and O'Toole, 2022). The EU is a major supplier of shark fins to Asian markets, with discrepancies in the reports that range from 1,650.08 to 2,318.18 metric tons of fin exports than the ones reported (Shea, Slee, and O'Toole, 2022). Shark catches are considered 3–4 times higher than the ones recorded by the United Nations Food and Agriculture Organization (FAO) (Dulvy et al., 2008).

The ongoing digital revolution is reshaping education, with children increasingly using technology in their daily lives, beyond traditional classroom settings (Collins & Halverson, 2018). Early education is vital for raising awareness about pressing issues, such as shark conservation. According to Piaget's stages of development, shown in Table 1, the Concrete Operational phase, occurring between ages 7 and 11, is characterized by enhanced logical thinking and organization (Berk, 2015). This phase presents an ideal opportunity to address important topics, like shark conservation.

Children often perceive sharks negatively, viewing them as aggressive and dangerous (Warren & Yoho, 2018). Changing these perceptions can not only increase knowledge but also influence family attitudes towards these animals (Damerell, Howe, and Milner-Gulland, 2013), potentially advancing the field of perception change through interactive digital tools. Serious games offer a compelling method to achieve this by providing engaging and enjoyable learning experiences that tap into children's natural curiosity and motivation (Zhonggen, 2019; Sudarmilah et al., 2018; Anastasiadis, Lampropoulos, and Siakas, 2018).

Exploring the potential of universal and adaptable games according to diverse player types could enhance engagement and effectiveness (Streicher & Smeddinck, 2016). This personalized approach aims to align with varied motivations, promoting effective learning and fostering a deeper understanding of conservation issues (Papanastasiou, Drigas, Skianis, and Lytras, 2017).

Serious games, which integrate entertainment with educational content, represent a promising approach to engaging audiences, particularly children, during their formative years when behavioral changes are most likely (Clark et al., 2011; Hungerford & Volk, 1990). These games can address complex issues like shark conservation in an engaging and effective manner. Although there's limited research about shark conservation serious games, there are multiple about the broader

Table 1 Piaget's phases of development (Piaget, 2000)

Phase	Ages (Years)	Characteristics
Sensorimotor stage	0–2	Infants and toddlers perceive the world through their physical interactions with the environment. They progress from basic reflexes to a coordinated set of behaviors
Preoperational stage	2–7	Young children build an understanding of permanent objects, use mental symbols, and develop language through dramatic play. Social and rule-based games emerge as peer interactions grow
Concrete operational stage	7–11	Children's reasoning becomes more logical, flexible, and organized. They can classify objects, understand others' thoughts (theory of mind), and begin to consider intentions in moral judgments
Formal operational stage	12+	Adolescents think systematically, reason abstractly, and understand ethics and science. They can form hypotheses and recognize that rules stem from mutual agreement

concept of marine conservation (Colleton et al., 2016; Panagiotopoulou et al., 2021; CJ et al., 2018).

This study focuses on the development of a serious game designed with and for children aged 7–11, who are in the Concrete Operational stage of cognitive development, as defined by Jean Piaget. As mentioned previously, at this stage, children begin to think more logically about concrete events, understand the concept of conservation, and develop a clearer sense of rules and morality (Berk, 2015). The game, limited to 30 min to suit children's attention spans (Altun, Hazar, and Hazar, 2016), uses engaging gameplay to challenge misconceptions and foster a deeper appreciation for sharks as essential and fascinating creatures.

Through the use of adaptive learning mechanisms, the game tailors the experience to the individual characteristics of each player, ensuring that the content is both accessible and engaging for diverse audiences. This personalized approach enhances the educational value of the game, as it allows children with different learning styles and abilities to fully participate in the experience (Papanastasiou, Drigas, Skianis, and Lytras, 2017). To further explore this personalization, the Hexad framework of player typologies was incorporated into the study (Diamond, Tondello, Marczewski, Nacke, and Tscheligi, 2015). The purpose of incorporating the Hexad framework was to explore potential alignment between player typologies and patterns in game metrics or preferences in some in-game elements in-game elements. Specifically, we aimed to determine whether certain elements of the game resonated more strongly with specific motivational types and if the game is sufficiently adaptable to meet the motivations of different player types.

In summary, this study contributes to the growing body of research on serious games and environmental education by exploring how interactive, technology-driven learning experiences can reshape children's perceptions of sharks. The goal is to not only increase knowledge but also inspire positive behavioral changes that support the conservation of sharks and, by extension, the health of marine ecosystems. As young players engage with the game, they are encouraged to become advocates for shark protection and conservation, paving the way for a more informed and compassionate approach to wildlife conservation in the future.

This article significantly expands upon a 2024 conference paper from the authors (Costa, Boaventura, Machado Alexandre, and Santana, 2024) by providing a more comprehensive presentation of the developed serious game, incorporating additional experimental results, and offering a deeper analysis and discussion. This article is organized as follows. In Section 2, the related work is presented and analyzed. Then, Section 3 presents the designed and developed serious game. Section 4 presents the evaluation procedure and analyzes the obtained results. Finally, Section 5 draws some conclusions and presents future work directions.

Related work

This study has a multidisciplinary nature, there are four key areas: sharks, children, game personality types, and serious games.

Relevant studies

This section explores a spectrum of articles and studies relevant to the development of the present study, focusing on the utilization of serious games to alter children's perceptions and enhance their knowledge about sharks. While the literature lacks a specific focus on serious games and sharks, several studies provide valuable insights into environmental awareness and conservation efforts. Each of the following paragraphs will further explain studies that related to this project.

Warren and Yoho (2018) conducted a study to assess how storybooks could change children's negative perceptions of sharks. Using a pre-test/pos-test design, children read a book about Sand Tiger Sharks (Carrick, 1979), incorporating personal connection text and factual information. The study found that incorporating personal connection text in storybooks about Sand Tiger Sharks led to more positive perceptions among children. After reading the books, children used terms like "helpers" and "boss of the ocean" to describe sharks, indicating a shift towards viewing them in a more favorable light. This study (Warren & Yoho, 2018) integrated methods such as three-word associations to evaluate changes in perception, which informed the methodological design of the project.

Rossano et al. (2018) introduced a serious game designed for primary school children to educate them about marine litter and endangered species in the Mediterranean Sea. The game aimed to cultivate ecological skills and positive environmental attitudes among students, with initial findings from pilot studies showing strong appreciation and perceived usefulness among both students and teachers. Their study highlighted the effectiveness of the game in enhancing ecological knowledge and fostering environmental attitudes among primary school students.

Veronica and Calvano (2020) developed a serious game and an explanation video to promote sustainability behaviors among children, specifically addressing marine litter Mediterranean sea. Evaluations demonstrated that these educational tools effectively increased children's awareness and knowledge of marine conservation issues, highlighting the potential of game-based learning to foster sustainable practices and environmental stewardship.

Additionally, Hill et al. (2021) examined how a serious game could alter children's perceptions and behaviors regarding COVID-19 preventive measures. The study found that serious games could effectively enhance participants' awareness and adherence to preventive practices, such as social distancing, mask-wearing, and hygiene. The game led to significant improvements in participants' understanding of these measures and observed behavioral changes. Furthermore, it was noted that serious games increased engagement and motivation compared to traditional educational methods, suggesting they are a valuable tool for public health education.

Lastly, Tsoi et al. (2016) investigated the perceptions of 11–12-year-old primary school students in Hong Kong regarding sharks and their ecological significance. The study highlighted that these students had limited knowledge and held misconceptions about sharks. The study emphasized the need for long-term educational efforts to improve public understanding and manage the demand for shark fins, especially given the cultural context in Hong Kong. This research provides important baseline data for designing effective educational interventions aimed at enhancing shark conservation awareness among younger generations.

These findings collectively indicate that interactive educational tools, such as serious games, can effectively enhance children's understanding of environmental issues and encourage positive attitudes towards conservation efforts.

Discussion

The importance of this project lies in its innovative approach to addressing gaps in existing literature on environmental education (Warren & Yoho, 2018; Carrick, 1979; Rossano, Roselli, and Calvano, 2018; Veronica & Calvano, 2020; Hill et al., 2021; Tsoi, Chan, Lee, Ip, and Cheang, 2016). While previous research has explored the use of serious games and educational tools to promote environmental awareness and behavior change, there is a notable absence of studies focusing specifically on altering children's perceptions of sharks through interactive media. The present study aims to fill this gap.

Although previous studies have shown that serious games can effectively raise awareness of marine conservation and promote sustainable behaviors among children, they have not specifically targeted sharks, an area where fear and misinformation are particularly prevalent. Therefore, the present study contributes to the field by not only focusing on shark education but also exploring the role of personality types in shaping how children interact with and learn from serious games.

Additionally, the study's novelty lies in its focus on using a serious game to specifically address children's perceptions and knowledge of sharks, a subject often shaped by negative stereotypes in existing marine-themed games, where sharks are commonly portrayed as villains. Our approach is further distinguished by the use of mixed evaluation methods, combining quantitative questionnaire data with a qualitative three-word association task. This dual-method strategy provides nuanced insights into children's cognitive and emotional responses, offering an innovative contribution to the field of serious games in marine education, particularly in relation to sharks, which are often subject to fear and widespread misconceptions. Furthermore, to enhance acceptance and engagement, children from the target audience were actively involved in the game's design phase..

Shark heroes: game design and development

Participatory design approach

Participation of schools

In order to provide a more comprehensive and well-rounded study, several schools were selected to participate in different phases of the research process. Each institution played a pivotal role in contributing valuable insights and feedback, which were essential for refining and validating the educational game developed in this study.

By involving multiple schools, the study aimed to gather data from a diverse range of students, ensuring that the results would be broadly applicable and reflective of various educational settings.

Fig. 1 illustrates the different schools that participated in this study, highlighting the specific iterations in which each school was involved. It also details the number of children who took part in each phase (there were no repetitions of participants within sessions).

Brainstorming in schools

During the early design phase, several initial ideas were considered; however, concerns about their potential complexity for the target age group led to the adoption of a participatory design approach. This method not only fostered a more inclusive development process but also enhanced the game's content by integrating the ideas and creativity of children in Piaget's Concrete Operational stage. Through their active participation in brainstorming sessions and iterative development phases, the game's final version was thoughtfully shaped to promote positive perceptions of sharks among young players.

The general idea of the serious game was designed and developed with active participation from a group of 20 children, comprising 12 girls and 8 boys with ages between 8 and 10, ($AVG = 9.10$, $STD = 0.64$, where AVG stands for average and STD for standard deviation of the ages). Only four of the children are non-Portuguese, with the majority being Portuguese children. The participatory design approach was used during this phase, which took place in the children's schools to ensure they were as comfortable as possible. This also helped maintain their parents' comfort with the children participating in the experiment, ensuring the game's engagement and effectiveness for the target audience (Dindler, Smith, and Iversen, 2020). The process began with a brainstorming session aimed at understanding children's perceptions of sharks and gathering their ideas for a game that could help change negative perceptions and increase some previously not obtained knowledge.

During the initial brainstorming session, the children were asked their opinions about sharks. They were questioned about their views on sharks, estimated how many sharks they think die in an hour, and identified some of the biggest threats sharks face today. This approach was designed to surprise the children,

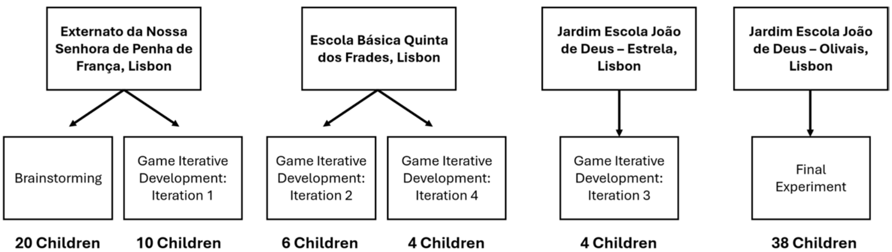

Fig. 1 Scheme showing the different phases throughout the schools

increasing their curiosity and awareness of the importance of sharks in marine ecosystems, while addressing common misconceptions about their danger to humans. This discussion aimed to inform and inspire the children, setting the stage for their creative input. The children were then encouraged to share their ideas for a game that would educate other kids about sharks and promote a more positive image. To facilitate discussion, a shark stuffed animal was passed around, allowing children to speak one at a time in an orderly manner. All proposed ideas, regardless of their relevance to the study, were recorded on a board. Positive feedback was given to each suggestion to encourage children to share their thoughts openly. Later, these ideas were compiled and saved in an Excel sheet for data analysis. Notable suggestions included tracking sharks and monitoring their behavior through players placing trackers on them, arresting illegal fisheries by taking on the role of marine protectors, and removing plastic from the ocean to raise awareness about marine pollution and directly link environmental conservation with shark protection. Among the numerous suggestions, the most relevant ones were selected for inclusion in the game based on potential for an engaging experience and knowledge transfer. In addition to gameplay ideas, feedback was sought on the initial game environment. Children suggested various enhancements to make the game world immersive and engaging. Among their recommendations were adding assets like whales, large ships, more turtles, a wide variety of fish, and diverse species to enrich the game setting. All the suggestions from the children were carefully reviewed, and those deemed most relevant were incorporated into the game environment. Following this collaborative design phase, development focused on creating two mini-games that encapsulated the most promising ideas. These ideas aimed to maximize both enjoyment and educational value for the players.

Game iterative development

The final version of the game, described in the following sections, was developed through four iterative phases aimed at refining and enhancing the gameplay experience. Each phase included evaluations and the integration of feedback to improve subsequent versions. Additionally, the information in the game was reviewed and approved by a marine scientist with expertise in educating children within the target age group. In the initial phase, bugs were addressed, and adjustments were made to the in-game questions to improve knowledge retention and highlight the ecological importance of sharks.

Originally, a Smileymeter was used to gauge children's perceptions and knowledge of sharks, but it was found to cause confusion in some iterations. To address this, a simplified Likert scale was implemented, excluding the neutral "neither agree nor disagree" option. This change encouraged children to choose either "agree" or "disagree," similar to the approach used in the Progress in International Reading Literacy Study (PIRLS) questionnaire.

Final game version

This section offers an overview of the game's final version and components, which were a result of continuous refinement throughout the iterative development phases, discussed in the previous section.

The game, developed using the Unity engine, was designed to deliver an immersive experience tailored to be used with a PlayStation 2 controller (DualShock 2). The decision to use a computer connected to a DualShock 2 controller was made due to its flexibility, portability, and the higher engagement it offers, compared to the use of a touchpad and keys combined, particularly for children. Early stages of the study demonstrated that this setup was quickly adopted, intuitive and enjoyed by the target audience. The game features a structured progression through three distinct scenes, each crafted with specific educational and gameplay objectives to ensure that players remain engaged while also learning valuable information. Additionally, considering that the mean attention span of children between the ages of 7–10 is around 20 minutes and 10–12 year olds is between 25–30 minutes, the decision made was that the mini-games being developed last no longer than 30 minutes in total, as this aligns with the upper limit of the desired attention span range for children aged 7–11.

After this brief introduction to key game design decisions, the following sections will detail the game environment, phases of the game and additional gameplay features and educational enhancements as well as how the data collection was done in-game.

Initial scene

The initial scene serves as an introduction to the game's educational content, where players encounter a shark knowledge and perception questionnaire. This initial interaction is crucial for setting the stage for the learning experience and the scene, depicted in Fig. 2, was crafted to engage and captivate players.

The initial scene features a water shader that realistically simulates an oceanic environment, complemented by a skybox that enhances the authenticity of the sky. A boat, scripted to simulate wave motion, to further immerse players in the environment. Central to this scene is the diver character (made with (Ready Player Me, 2024)), who represents a marine biologist acting as a helper, by giving instructions, motivation, to the player throughout the game. This character is animated with series of animations (made with (Mixamo, 2024)), randomly selected from a predefined set whenever the dialogue text changes. This initial scene not only provides players with instructions but also was made to immerse the players in the game's setting, preparing them for the challenges that lie ahead.

Main scene

The main scene is enriched by high-quality models and animations imported from Sketchfab (2024) via a the platform where the game was developed, Unity (Unity Technologies, 2024), ensuring detailed and realistic visual representations. Initially, a broader variety of fish species was included, but these were later removed after a

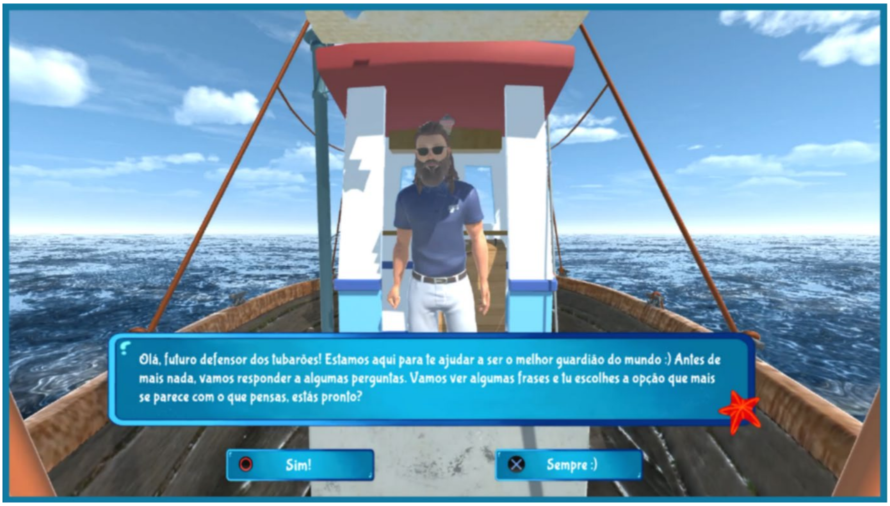

Fig. 2 Initial scene with an embedded questionnaire - A diver explains how the initial scene will proceed and asks the player if they are ready

specialist in marine sciences identified that such species would not naturally coexist in the depicted environment.

Upon entering the main scene, the player is presented with a set of instructions from a diver, who will assist them throughout the mini-games. After the player presses a button following the final dialogue, the first mini-game begins.

The main scene is bounded by four planes forming a box around the play area, ensuring players remain within the designated space. If players approach these boundaries, they are redirected to the center of the game area with a warning message to maintain smooth gameplay. Additionally, the boundaries act as an adaptive mechanism: if a player fails to track a shark (the mini game that will be explained in the following paragraph) within 60 s, either from the previous tracking or the start of the game, the boundaries will shrink. This reduces the playable area, increasing the likelihood of encountering a shark.

The first mini-game, *Tracking Sharks*, depicted in Fig. 3, has players attach tracking devices, equipped with an antenna and a health status light, to different shark species. These devices provide real-time feedback on the sharks' conditions. The tracking process is initiated when the player approaches an untracked shark. Upon detection, a canvas prompts the player to press a button on the DualShock 2 controller, activating a secondary camera view that follows the shark from the side, allowing the player to monitor the tracking process. The tracker is designed to make contact with the shark's fin using a collider mechanism to ensure it remains attached. If the player fails to track the shark successfully, the tracker encounters a secondary collider, triggering a motivational message to encourage persistence before resetting to its original position. Success in tracking shifts the camera back to the diver's original perspective. To complete this task, players must successfully track a diverse range of sharks, including two blacktip sharks,

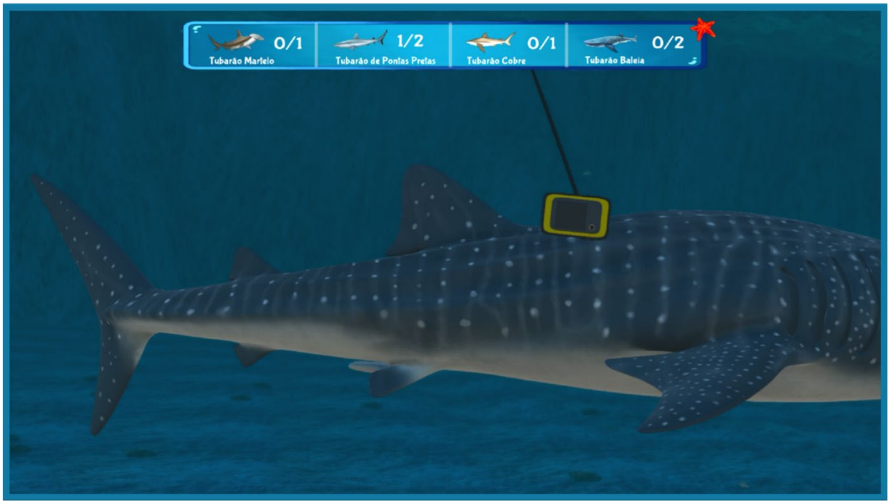

Fig. 3 First mini-game (*Tracking Sharks*): Tracking shark task

two whale sharks, one copper shark, and one hammerhead shark, each presenting unique tracking challenges, such as velocity of the tracker and distance to the shark. As players track a specific shark, random facts about the species appear on the left side of the screen for a few seconds, allowing enough time for the player to read and absorb the information. Later, some of these facts are turned into questions during the second task, reinforcing the educational material and testing the player's retention in an interactive way.

Fig. 3 depicts a side view of a whale shark as the player attempts to attach a tracker to its dorsal fin. After tracking a shark, players can monitor its movements and behaviors. They can also check the shark's health level based on the color of the tracker's light (red for injured, green for healthy as shown in Fig. 4).

The first mini-game seeks to demystify sharks and highlight their vital role in marine ecosystems. By allowing players to track sharks, it fosters a more personal connection with these sea creatures. The facts presented throughout the game intend to enhance the players' knowledge and understanding of sharks.

After the tracking mini-game, players progress to rescuing injured sharks in the second mini-game, *Helping sharks*. The children search the water's surface for a boat to retrieve a radar. If players move above the water's surface, a different audio track plays, simulating sounds of the outside world such as seagulls and wind. Diving back into the deeper waters transitions the audio to reflect the ambiance of the deep ocean, enhancing immersion and realism.

The player retrieves then the radar, which displays the locations of tracked sharks on a canvas centered in the player's view. The radar reveals previously hidden objects, such as hooks and fishnets, with injured sharks marked by a red tracker color to denote urgency. This phase emphasizes the conservation message by highlighting the need for timely intervention. Players must locate and interact with these injured sharks to provide assistance.

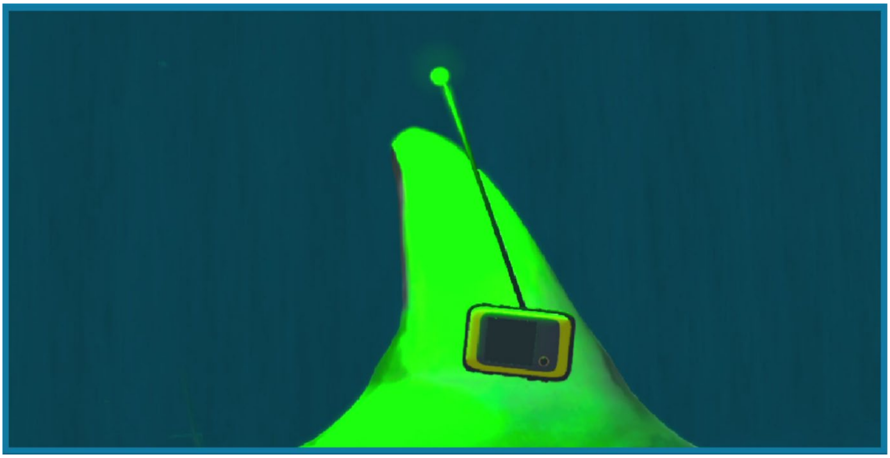

Fig. 4 Tracker showing green light meaning the shark is in a healthy state

When a player approaches an injured shark, a canvas appears, prompting the player to begin a questionnaire related to saving the shark. This questionnaire, depicted in the Table 2, is composed of questions drawn from a list of educational content, has been reviewed to ensure accuracy and relevance.

The questions from this table are answered by choosing one of two options, one being right and the other wrong. If players answer incorrectly, motivational audio cues are played to keep them engaged and encourage continued effort.

Successfully answering three consecutive questions results in the removal of the nets or hooks impeding the shark's movement. The tracker's color changes back to green, both on the physical tracker and the radar, signaling the successful

Table 2 List of questions that are randomly selected to be asked during the second task

ID	Question asked
SQ1	What do whale sharks have at the surface of their eyes?
SQ2	What is the length of a whale shark?
SQ3	Sharks survived how many mass extinctions?
SQ4	How many shark species are there?
SQ5	What's the biggest fish in the world
SQ6	What are blacktip sharks known for?
SQ7	Human kill how many sharks per hour?
SQ8	Are sharks older than dinosaurs?
SQ9	Sharks usually bite for..
SQ10	Sharks are usually killed by the value of their..
SQ11	The shark meat market has a value of..
SQ12	How do shark help maintaining the health of the oceans
SQ13	Why are sharks considered the guardians of the ocean?
SQ14	What would happen if sharks disappeared?

Fig. 5 Second mini-game (*Helping Sharks*): Saving sharks by answering to questions about them - The question asked is: What are the blacktip sharks are known for? In this case, the player wrongly answered "For their velocity"

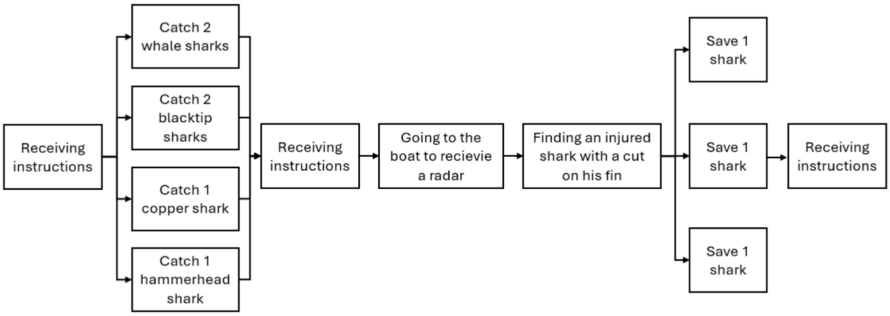

Fig. 6 Main Scene Workflow

completion of the rescue. Once all three injured sharks are rescued, players receive a congratulatory message, marking the transition to the final scene.

The mini-game, *Helping Sharks*, highlights the impact of pollution on marine life and increases the environmental education. By trial and error in some of the questions or using previously gained knowledge children can finalize the task while retaining the knowledge they previously did not have. Fig. 5 shows the player answering the questions as well as the radar described previously, indicating where the tracked sharks are located, in the right upper corner of the image.

Fig. 6 depicts the sequence of tasks the player goes through in order to advance to the next scene, once the player finishes all, they move to the next scene (Final scene). This includes the initial instructions provided by the diver, tracking six sharks of the specified species, receiving additional instructions for completing the second mini-game, retrieving the radar from the boat, locating and saving three sharks, and finally receiving instructions and congratulatory messages to proceed to the next scene.

An additional scenario was introduced to address a knowledge gap children had regarding sharks being targeted for their fins and to raise awareness about this critical issue. In this scenario, if the camera captures a specific shark, it zooms in to reveal a noticeable cut on the shark's fin. This visual cue indicates that the shark was targeted by a fisherman attempting to remove its fin but managed to escape. To further emphasize the message that millions of sharks are killed every year, a text panel is displayed, informing players that millions of sharks are killed annually for their fins, often to make Chinese shark fin soup.

Final scene

In the final scene players complete a follow-up questionnaire to assess their knowledge and perceptions of sharks after completing both mini-games, allowing for comparison with their pre-game responses. Additionally, the sky now showcases a sunset, contrasting with the initial scene and indicating that the player has spent several hours in the water completing tasks. This choice was made not only to visually differentiate the two scenes for the player but also to enhance the overall realism of the experience.

After completing the questionnaire, children are awarded a certificate and a pamphlet. The certificate recognizes achievement, while the pamphlet offers valuable information on shark conservation. It acknowledges the player as a shark guardian serving as a reminder of their commitment to protecting sharks and ensuring a safe future for these creatures. In addition to this recognition, the pamphlet provides practical and actionable ways for players to contribute to shark conservation efforts in their everyday lives. It suggests avoiding shark meat and refraining from purchasing products made from shark parts. Players are encouraged to check labels for scalene, a shark-derived substance often found in cosmetics and other products, helping them make informed decisions. Furthermore, the pamphlet highlights the importance of sharing knowledge about sharks with friends and family, fostering a broader awareness of shark conservation issues.

Game workflow

A clear understanding of the game's structure is essential to grasp the progression of in-game activities. The Fig. 7 separates the different activities performed within the game environment, providing a comprehensive overview. This depiction helps to understand the sequence of actions in-game activities.

Evaluation

This section details the experimental design used to assess the educational impact of the game's final version, described in Section 3.2, on Portuguese children, as well as the its results. It outlines the evaluation study's methodology,

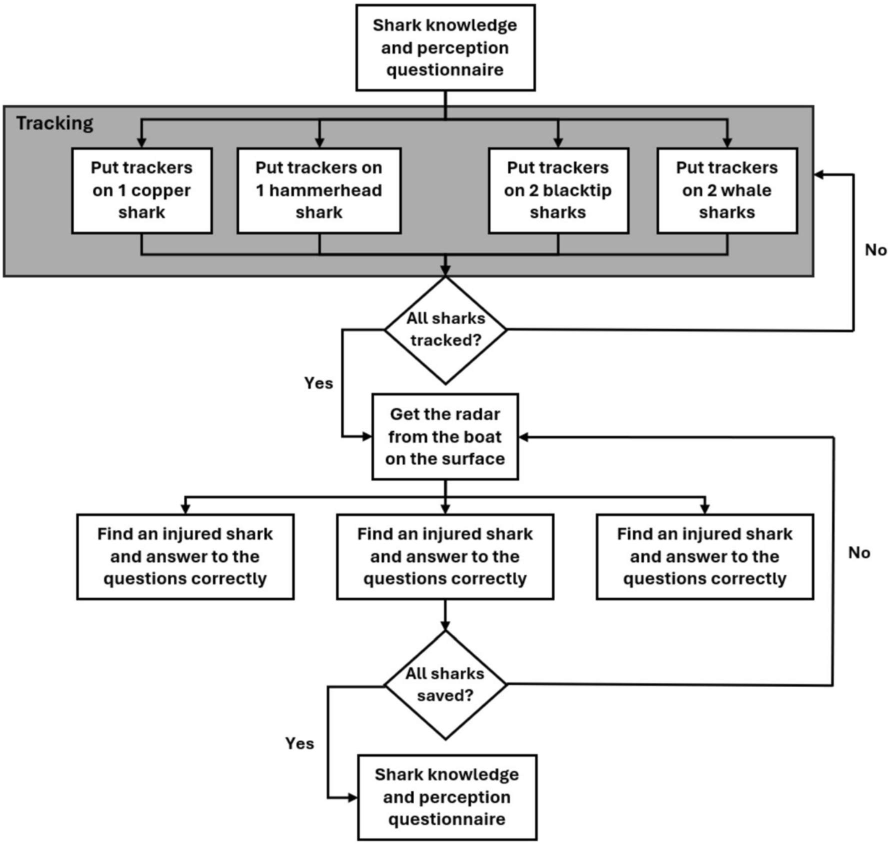

Fig. 7 Workflow of the game

which involved an initial questionnaire, an in-game survey, and post-game evaluations as well as any ethical considerations that had to be taken.

The key components of this experiment include tracking children's perceptions about sharks, engaging them in interactive gameplay, and analyzing shifts in their knowledge and attitudes towards shark conservation. Changes are examined in children's knowledge and perceptions of sharks by analyzing their questionnaire responses and the words children used to describe sharks before and after playing the game. Additionally, the relationship between different player types and their game performance is explored.

It is also crucial to emphasize the importance of ensuring that the final experiment was conducted with children who had not previously worked closely with the game. This precaution was necessary to eliminate any potential biases that could arise from prior familiarity with the game's content and mechanics.

Experiment design

The final study included 38 Portuguese children, which is a sample size comparable to other studies in HCI and serious games research (e.g., (Warren & Yoho, 2018; Carrick, 1979; Rossano, Roselli, and Calvano, 2018; Veronica & Calvano, 2020; Hill et al., 2021; Tsoi, Chan, Lee, Ip, and Cheang, 2016)). This sample is comprised of 23 boys and 15 girls, with ages ranging from 9 to 11 ($AVG = 9.4$, $STD = 0.55$). The experiment was carried out in a single session, with no breaks between different phases, to minimize potential biases from exposure to media or via peer interaction. Each child participated in the experience individually, in a classroom isolated from the colleagues. The experiment began with each child completing an initial questionnaire aimed at gathering demographic information. This questionnaire included questions about the child's age and gender for statistical analysis purposes. To understand the child's initial mindset and preconceived notions about sharks, the questionnaire also featured a section in which children were asked to list three words that came to mind when they thought of sharks. This approach was intended to assess children's pre-game qualitative perceptions of sharks and was taken from a previous study carried out by (Warren & Yoho, 2018), while we acknowledge that self-reported measures like Likert scales and word associations can introduce subjectivity, we selected these tools because they are particularly suited to evaluating children's attitudes and perceptions, which are the focus of this study. Additionally, the child's player type was determined using the questions in Table 3, which enabled the investigation of correlations between their preferred aspects of the game, retrieved parameters, and their user type according to the Hexad model, a framework categorizing users into distinct types based on their motivations and preferences in gamified systems (Diamond, Tondello, Marczewski, Nacke, and Tscheligi, 2015). In order to ensure that the children understood well the questionnaire, it was first translated by a bilingual person to Portuguese and then translated back by another in order to ensure that the translation would be as valid as possible. In addition to this,

Table 3 Questions to assess user's Hexad player type

ID	Question
Q1	It is important to me to follow my own path
Q2	Being independent is important to me
Q3	I enjoy emerging victorious out of difficult circumstances
Q4	I enjoy group activities
Q5	It makes me happy if I am able to help others
Q6	I like being part of a team
Q7	Rewards are a great way to motivate me
Q8	I see myself as a rebel
Q9	If the reward is sufficient, I will put in the effort
Q10	I dislike following rules
Q11	I like mastering difficult tasks
Q12	The well-being of others is important to me

the children also observed the questionnaire and answered the questions in order to check whether they were easily understood by children or not.

Following the initial questionnaire (Table 3), the child participated in an in-game survey. This in-game survey, shown in Table 4, was tailored to assess the child's existing perceptions and knowledge about sharks. Previously validated by a specialist in the area of education and marine science this questionnaire included questions designed to evaluate children's awareness of sharks' roles in marine ecosystems, their understanding of the threats sharks face, and any misconceptions they might hold about these sea creatures.

The responses were evaluated on a scale from −2 to 2, based on the Likert Scale ranging from totally agree to totally disagree. For example, if a child answered "totally agree" to the statement "all sharks are dangerous to humans," the response would be assigned a value of −2, indicating a negative perception. This approach differs from the usual 0 to 5 classification, emphasizing whether the perception is negative or positive, as well as if the knowledge acquired is factually wrong or right by using the negative or positive signal with this intent. Additionally, the neutral option was removed to encourage children to make a definitive choice rather than opting for a neutral response.

Once the initial data collection was completed, the child was introduced to the game environment. The introduction included a brief oral explanation on the basic movement and rotation commands necessary to navigate the game.

The child then proceeded to complete the two designed tasks. Upon completing the game, the child was prompted to retake the initial perception and knowledge questionnaire. This post-game survey was conducted within the game environment and aimed to measure any changes in the child's perceptions and knowledge about sharks. The results from this questionnaire provided quantitative data on the educational impact of the game.

In addition to the post-game survey, the child was presented with a pamphlet containing practical tips on how to contribute to shark conservation in their daily life. This pamphlet served as an educational tool to extend the learning experience beyond the game. To recognize their efforts, the child received a certificate naming

Table 4 Questionnaire to assess children's current perception and knowledge of sharks

ID	Question
SQ1	All sharks are dangerous to humans
SQ2	Sharks are important to maintain the ocean's health
SQ3	If I come across a shark I will always be attacked
SQ4	It is necessary to protect sharks
SQ5	Humans are shark's favourite food
SQ6	I hate sharks and I am scared of them
SQ7	The ocean's health stays fine without sharks
SQ8	I want to know more about sharks
SQ9	Sharks are bad animals and we should kill them all
SQ10	Many sharks are captured for the value of their fins

them an official guardian of sharks, encouraging continued interest in shark conservation.

Finally, the child was asked to reflect on their game experience by writing three words that now come to mind when they think of sharks. This repetition aimed to capture any shifts in perception. They were also asked to draw their favorite and least favorite parts of the game providing qualitative insights into what aspects of the game were most engaging or challenging. In Fig. 8 it is possible to see the workflow throughout the whole experiment, providing a visual guide to the sequential steps and activities children engage in, not only in the game but before and after as well.

Data Collection

The game systematically collects player data, which is recorded in CSV files for each task and questionnaire, as outlined in Table 5. Data from the same session is appended to the existing line, while new sessions generate a new line.

These data is analyzed to explore relationships with player types, providing insights into player behavior and learning outcomes. The analysis aims to confirm that no significant correlations were found, indicating that, for this sample of participants, no notable differences in gameplay were observed. If confirmed, this would indicate that the game successfully adapted to the different player types within the sample.

Ethical considerations

The project, which involved children as participants, was reviewed and approved by ISCTE Ethics Council with approval number 45/2024. The review process prioritized the protection of children's rights, including the securing of informed

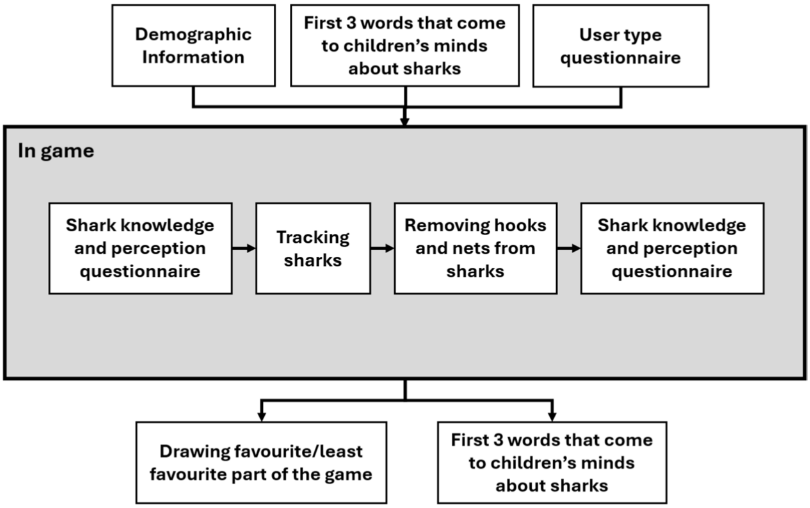

Fig. 8 Workflow of the experiment

Table 5 Game parameters retrieved

ID	Game parameter
P.1	Time that it takes to conclude task 1
P.2	Number the borders were shrinked
P.3	Number of times the player misses the fin while trying to track a shark
P.4	Additional sharks the player tracks
P.5	Number of wrong answers while trying to save shark number 1 (In task 2)
P.6	Number of wrong answers while trying to save shark number 2 (In task 2)
P.7	Number of wrong answers while trying to save shark number 3 (In task 2)
P.8	Time that it takes to conclude task 2

parental consent and the assurance of data confidentiality. Formal authorization was first obtained from the participating schools, followed by informed consent from the children's legal guardians. Guardians were fully briefed on the study's objectives, data privacy measures, and the voluntary nature of participation. Before starting the experience, children were explicitly reminded of their right to withdraw at any time without any consequence, ensuring that participation remained entirely voluntary.

To reduce any potential stress or discomfort, such as anxiety about answering questions "incorrectly" or being influenced by peers, the study was conducted individually with each child. Only minimal demographic data (age and gender) were collected, and no audio or video recordings were made. Questionnaires were completed on paper and labeled with unique, randomly generated identification codes, ensuring participant anonymity throughout all phases of the study.

In line with institutional ethical guidelines, all data were stored on a password-protected encrypted computer, accessible only to the research team. Participants' identities were anonymized using coded identifiers and no personally identifiable information was collected, stored, or used in data analysis or reporting. These procedures ensure the protection of children's privacy and strengthen the ethical integrity of the study.

Perception and knowledge of sharks

To evaluate the impact of the educational game on children's knowledge and perception of sharks, both questionnaire responses and the three words children associated with sharks before and after playing the game were analyzed. Table 6 summarizes the obtained results, which are detailed in the following paragraphs.

The knowledge and perception scores scale is from −10 to 10. The differences in knowledge scores before and after for each child were calculated, and then the mean difference across all children was determined. The results show a significant increase in knowledge ($AVG = 3.92$, $STD = 3.03$), with a detailed statistical analysis of these results being provided below.

Table 6 AVG and STD of the difference in the parameters before and after playing the game

Parameters	Scale	AVG	STD
Knowledge questions	[−10,10]	3.92	3.03
Perception questions	[−10,10]	1.60	2.47
Positive words	[−3,3]	1.34	1.12
Negative words	[−3,3]	−0.87	0.93

Changes in perception were assessed by calculating the mean difference in perception scores. The analysis revealed a more positive view of sharks after the game (*AVG* = 1.60, *STD* = 2.47).

The words the children provided before and after gameplay were categorized as positive, negative, or neutral. Neutral words carried no positive or negative connotation and were simply descriptive.

The results of the difference between before and after the child played the game were (*AVG* = 1.34, *STD* = 1.12) for positive words and for negative words (*AVG* = 0.87, *STD* = 0.93).

The most commonly used negative words were "scary" and "fear," each mentioned by 21.05% of the children. The positive word "help," used by 13.16% of the children, conveyed the idea that sharks need assistance as explained by the children when questioned about it. Figs. 9 and 10 display the top ten words used before and after gameplay, respectively. These data show the educational game's effectiveness in enhancing children's knowledge about sharks and fostering more positive perceptions of these important marine creatures.

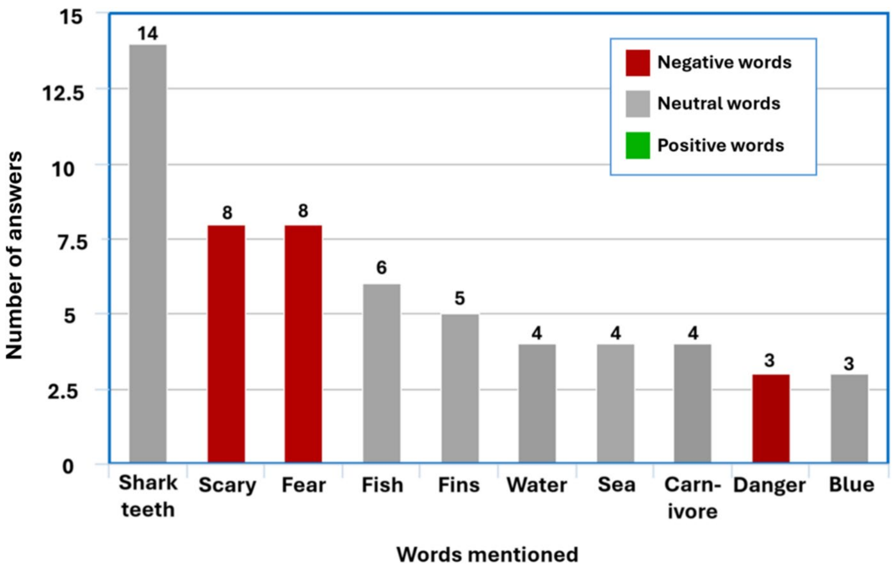

Fig. 9 Top 10 words selected by the children before playing the game

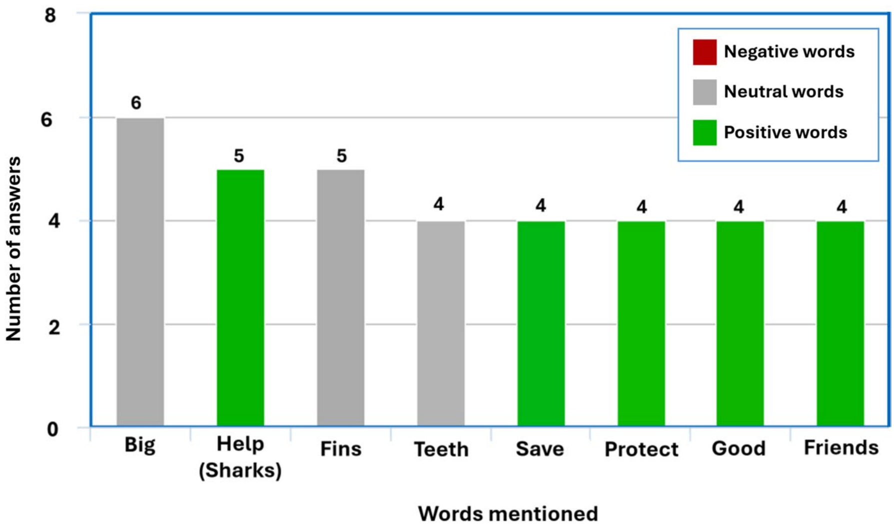

Fig. 10 Top 10 words selected by the children after playing the game

To determine the statistical significance of the obtained results, the Shapiro-Wilk Test, which is a normality test, was used to assess whether the perception data followed a Gaussian distribution and to further notice if it was valid to apply the paired t-test, given its effectiveness for smaller to moderately sized samples (up to around 50). With $p > 0.05$ ($p = 0.052, n = 38$), it is not possible to reject the null hypothesis that the data is normally distributed.

To further gather evidence in favor of the data following a Gaussian distribution, a Q-Q plot was created, as illustrated in Fig. 11, with dots representing the predicted residuals and the line representing the line of identity that provides the fit for the points. If the data follows a normal distribution, the points will align along the 45-degree line of identity, deviations from this line suggest a non-normal distribution. A paired *t-test* was performed to compare perception scores before and after the game, and Confidence Intervals (CI) were calculated accordingly. The results showed statistically significant changes for a 99% confidence level ($p < 0.01$, $CI = [0.74, 2.36]$, $n = 38$).

The knowledge results did seem to follow a Gaussian distribution as well according to the Shapiro-Wilk test since $p > 0.05$ ($p = 0.497, n = 38$). Using Fig. 12, a Q-Q plot was created, with dots representing the predicted residuals and the line indicating the line of identity, to further assess whether the data followed a normal distribution. The plot shows that the dots align with the line, indicating that the data passes the normality test. A paired *t-test* was then performed and indicated the output is statistically significant for a confidence level of 99% ($p < 0.01$,, $CI = [2.93, 4.92]$, $n = 38$). In conclusion, both statistical tests confirmed the significance of the differences.

In order the check if the values had a practical significant the Cohen's d value was used. Cohen's d was calculated for both knowledge and perception differences.

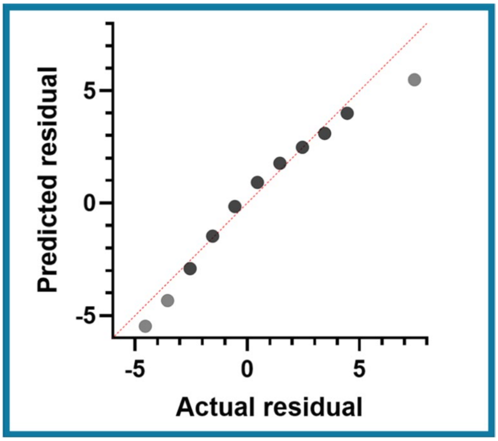

Fig. 11 Q-Q plot illustrating the distribution of perception differences

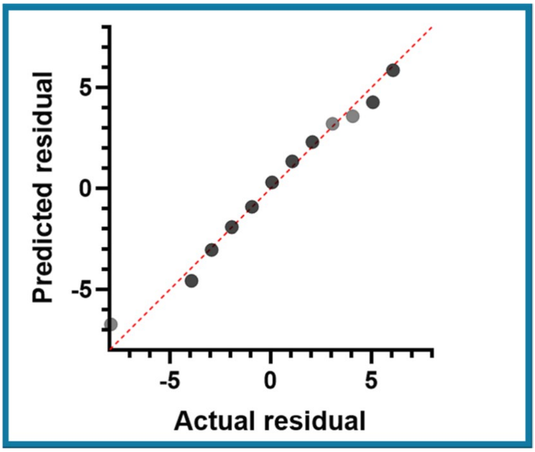

Fig. 12 Q-Q plot illustrating the distribution of knowledge differences

The knowledge data had a Cohen's $d = 1.33$, indicating a large effect size (Cohen's $d \geq 0.8$), while the perception data had a Cohen's $d = 0.64$, indicating a medium effect size ($0.5 \leq$ Cohen's $d \leq 0.8$) (Ellis, 2010).

User player type and retrieved metrics

In addition to its primary objectives, the study also investigated the relationship between different player types and their game performance and parameters. Firstly the distribution of different player types was analyzed (see Fig. 13).

It is important to mention that each child might have multiple player types, explaining why the numbers added surpass the number of participants in the phase. As seen in the Fig. 13, a significant amount of children have the Philanthropist (68.42%) as their player type based on the Hexad Model, followed by Socialiser

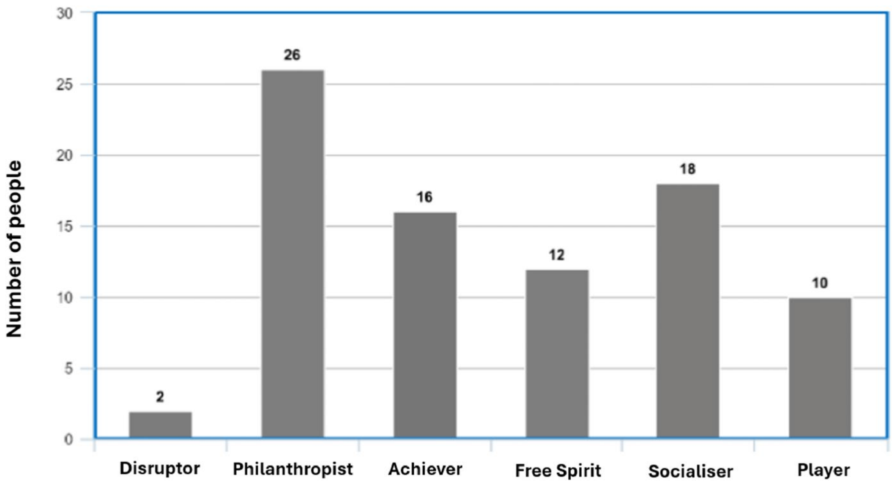

Fig. 13 Distribution of the different player types in 38 children, according to the Hexad model (Diamond, Tondello, Marczewski, Nacke, and Tscheligi, 2015)

(47.37%) and Achiever (42.10%) and very few children were identified as Disruptor (5.26%).

The next goal was to check if the game was effectively adaptable to every player independently of their player type and skill level. Due to the low number of Disruptors, this player type was removed from the performance in these tests.

This decision allowed for a clearer evaluation of how the game accommodates the more prevalent player types, ensuring no biases and that the adaptability and engagement of the game can be accurately measured across a broader spectrum of participants.

An evaluation of this relationship was carried out with (Jamovi Project, 2024). For this analysis, the Kruskal-Wallis One-Way ANOVA test was chosen. This test is used to find out if there are significant differences among three or more groups based on a specific variable which is the focus of interest. This variable should be continuous, meaning it can assume any value within a range. It is acceptable if the data is not perfectly normal or is skewed. However, the spread or variability of this variable should be similar across all the groups being compared.

In this analysis, each player type was assigned a specific number. If a player fell into more than one type, they were treated as if they were a different player but with the same characteristics. This allowed the test to consider all variations among the different player types.

Table 7 shows the p-value resulting from the Kruskal-Wallis test. There are no statistically significant differences between the various player types with respect to any of the game parameters examined ($p > 0.05$). In other words, whether a player is a novice or an experienced gamer, younger or older, or of any particular gender, their interaction with the game remains largely consistent across these variables.

The results indicate that the game design promoted adaptability and inclusivity. That is, the game's mechanics, challenges, and overall experience are effectively

Table 7 The p-values resulted from the Kruskal-Wallis One-Way ANOVA test the relationship between game parameters and player types

Game Parameter name	p-values
Gaming frequency	0.909
Taken time to complete Task 1	0.937
Sharks caught	0.985
Fins missed while tracking	0.813
Additional sharks caught (besides the ones initially asked to)	0.794
Answered to wrong questions in the 1 st Shark	0.986
Answered to wrong questions in the 2nd Shark	0.529
Answered to wrong questions in the 3rd Shark	0.876
Taken time to complete Task 2	0.947
Answer shark questions again?	0.628
Tracking sharks again?	0.841
Looking for injured sharks again?	0.559
Save them by answering questions again?	0.722
Repeat receiving the certificate?	0.559
Age	0.681
Gender	0.552

balanced and universally engaging, regardless of the player's background or skill level. One example of the game's adaptability features is its dynamic adjustment of the game area. If a player is unable to locate a shark to attach a tracker to within a specified time limit, the boundaries of the game area gradually shrink. This reduction in area makes it easier for the player to find a shark, as the space where the shark could be located becomes progressively smaller, bringing the player closer to their target. Furthermore, the lack of significant variation in performance and experience among different player types suggests that the game does not disproportionately favor any specific group, remaining accessible to a broad audience.

In summary, the findings suggest that the game is both adaptable and inclusive, catering to a diverse range of players without showing significant differences in performance or experience. Additionally, it is shown significant positive outcomes in terms of perception change and knowledge acquisition throughout the experiment.

Conclusion

The global decline in shark populations underscores the urgent need for innovative educational strategies that enhance conservation awareness and promote sustainable practices across generations. To address this critical challenge, this article presented a Unity-based serious game developed as an education tool that features two interactive mini-games. This tool was designed for children between 7 and 11 due to their currently acquired development phase, aiming to demystifying these apex predators and highlighting their vital role in preserving marine ecosystems.

Utilizing a participatory design approach, 20 were involved children in brainstorming and early game design sessions. This inclusive method ensured that diverse perspectives from the target group were considered, fostering creativity and inclusivity. By involving children, the aim was create a game that ensured that it was both engaging and educational.

One mini-game focused on the ecological role of sharks, using engaging challenges to illustrate their importance in maintaining the health of marine ecosystems. The other mini-game allowed children to experience the life of a shark, emphasizing the threats they face from human activities, such as overfishing and habitat destruction.

The final iteration of the game underwent rigorous testing with 38 participants, providing significant evidence of its impact. The findings demonstrate that the game substantially enhances participants' knowledge about sharks, as indicated by a notable increase in knowledge scores. Additionally, the game effectively cultivates positive perceptions of sharks, with participants showing improved perception scores post-gameplay. Qualitative insights from words associated with sharks before and after playing the game further validate these quantitative gains, revealing a significant shift towards more positive attitudes and decreased negative perceptions following interactive engagement.

The study examined the adaptation of the game with the correlations between player characteristics and game performance metrics, no statistically significant relationships was found between them, highlighting the game's adaptability. Overall, the study confirms that the serious game is an effective educational tool, successfully increasing knowledge and improving attitudes towards sharks, while demonstrating its ability to engage a diverse audience without being affected by individual differences in player profiles.

In conclusion, the serious game, developed for this project, represents an interactive educational tool that hopes to contribute significantly to environmental education and conservation efforts. By fostering empathy, deepening understanding, and promoting informed knowledge through engaging learning experiences, initiatives like this have the potential to inspire a generation of environmentally conscious citizens dedicated to safeguarding the biodiversity and ecological integrity of our oceans.

Naturally, the current study has certain limitations. Due to its limited temporal scope, a long-term assessment of the game's impact on children's knowledge and perceptions could not be conducted. Future research would benefit from extended follow-up assessments to evaluate the durability and retention of learning outcomes over time (e.g: one month after the intervention). In future work, it will be important to conduct additional tests with a larger and more culturally diverse sample of children to assess the generalizability of the positive outcomes observed. As the study was limited to participants in Portugal, its ability to account for cultural factors influencing children's perceptions of sharks is constrained. We acknowledge that cultural context can play a significant role in shaping attitudes toward animals and environmental themes, and future cross-cultural comparisons are essential to evaluate the broader applicability and educational impact of the game across different populations.

Another limitation is that the study did not analyze which specific aspects of the game, such as visual storytelling, factual content, or interactive gameplay, were most effective in driving changes in perception. While we gathered feedback on which parts of the game children enjoyed, this was not systematically linked to perception outcomes. Therefore, future research should aim to isolate and evaluate these components individually.

It is also relevant to explore the correlation between gender and different interactions with the game; for example, girls were observed to try to put the tracker in the center of the fin, while boys were more directed towards attaching it without particular concern for placement. Additionally, the relationship between player types and various game parameters recorded during gameplay (e.g., time taken, number of attempts to track a shark) would be interesting to investigate further. Analyzing these correlations aims to gain deeper insights into player behavior and preferences, further informing the development of effective educational tools.

Furthermore, future studies could benefit from involving children with Neurodevelopmental Disorders (NDD) to explore how the game might be adapted to enhance its inclusivity. Gaining insights into how these children interact with the game, particularly through methods such as eye-tracking, could provide valuable information for designing more accessible and effective educational interventions tailored to their specific needs.

To enhance the educational impact, the potential use of Virtual Reality (VR) and Augmented Reality (AR) can be also considered. VR can provide an even more immersive experience, allowing players to virtually dive into the ocean and interact with sharks in their natural habitat, while AR can bring elements of the game into the real world, enhancing engagement through interactive learning.

Finally, it will be important to expand the game's content and complexity based on feedback from both children and educators. This might include additional mini-games, more detailed information about different shark species, and scenarios that address broader environmental issues, such as climate change and plastic pollution.

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Data Availability The data sets used and/or analyzed during the current study are available from the authors on reasonable request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no Conflict of interest.

Ethical approval This work was approved by the ISCTE Ethics Council with approval number 45/2024.

References

Altun, M., Hazar, M., & Hazar, Z. (2016). Investigation of the effects of brain teasers on attention spans of pre-school children. *International Journal of Environmental and Science Education, 11*(15), 8112–8119.

Anastasiadis, T., Lampropoulos, G., & Siakas, K. (2018). Digital game-based learning and serious games in education. *International Journal of Advances in Scientific Research and Engineering, 4*(12), 139–144.

Berk, L. (2015). *Child development*. Pearson Higher Education AU.

Cardeñosa, D., Shea, S. K., Zhang, H., Fischer, G. A., Simpfendorfer, C. A., & Chapman, D. D. (2022). Two thirds of species in a global shark fin trade hub are threatened with extinction: Conservation potential of international trade regulations for coastal sharks. *Conservation Letters, 15*(5), Article e12910.

Carrick, C. (1979). *Sand tiger shark*. Clarion Books.

Carrier, J.C., Simpfendorfer, C.A., Heithaus, M.R. spsampsps Yopak, K.E. (2022). *Biology of sharks and their relatives*.

CJ, G., Pandit, S., Vaddepalli, S., Tupsamudre, H., Banahatti, V. & Lodha, S. (2018). Phishy-a serious game to train enterprise users on phishing awareness. *Proceedings of the 2018 annual symposium on computer-human interaction in play companion extended abstracts* (pp. 169–181).

Clark, D. B., Nelson, B. C., Chang, H.-Y., Martinez-Garza, M., Slack, K., & D'Angelo, C. M. (2011). Exploring newtonian mechanics in a conceptually-integrated digital game: Comparison of learning and affective outcomes for students in taiwan and the united states. *Computers & Education, 57*(3), 2178–2195.

Clarke, S. C., Magnussen, J. E., Abercrombie, D. L., McAllister, M. K., & Shivji, M. S. (2006). Identification of shark species composition and proportion in the hong kong shark fin market based on molecular genetics and trade records. *Conservation Biology, 20*(1), 201–211.

Colleton, N., Lakshman, V., Flood, K., Birnbaum, M., Mcmillan, K., & Lin, A. (2016). Concepts and practice in the emerging use of games for marine education and conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems, 26*, 213–224.

Collins, A., & Halverson, R. (2018). *Rethinking education in the age of technology: The digital revolution and schooling in america*. Teachers College Press.

Costa, M., Boaventura, D., Machado Alexandre, I. & Santana, P. (2024). A Serious Game to Increase Children's Awareness About the Vital Role of Sharks in Marine Ecosystems. *Proceedings of the International Conference on Graphics and Interaction (ICGI)* (pp. 1-8), https://doi.org/10.1109/ICGI64003.2024.10923731.

Damerell, P., Howe, C., & Milner-Gulland, E. J. (2013). Child-orientated environmental education influences adult knowledge and household behaviour. *Environmental Research Letters, 8*(1), Article 015016.

Diamond, L., Tondello, G., Marczewski, A., Nacke, L. & Tscheligi, M. (2015). The hexad gamification user types questionnaire: Background and development process. *Proceedings of the acm sigchi annual symposium on computer-human interaction in play.*

Dindler, C., Smith, R., & Iversen, O. S. (2020). Computational empowerment: Participatory design in education. *CoDesign, 16*(1), 66–80.

Dulvy, N. K., Baum, J. K., Clarke, S., Compagno, L. J., Cortés, E., Domingo, A., & Gibson, C. (2008). You can swim but you can't hide: The global status and conservation of oceanic pelagic sharks and rays. *Aquatic Conservation: Marine and Freshwater Ecosystems, 18*(5), 459–482.

Dulvy, N. K., Fowler, S. L., Musick, J. A., Cavanagh, R. D., Kyne, P. M., Harrison, L. R., & Francis, M. P. (2014). Extinction risk and conservation of the world's sharks and rays. *eLife, 3*, Article e00590.

Ebert, D., Fowler, S., & Compagno, L. (2013). *Sharks of the world: A fully illustrated guide*. Wild Nature Press.
Ellis, P. D. (2010). *The essential guide to effect sizes: Statistical power, meta-analysis, and the interpretation of research results*. Cambridge University Press.
Heithaus, M. R., Frid, A., Wirsing, A. J., & Worm, B. (2008). Predicting ecological consequences of marine top predator declines. *Trends in Ecology & Evolution, 23*(4), 202–210.
Hill, J., Corke, E., Salawu, M., Cotterell, E., Russell, M., Gibbons, J. & Karnik, A. (2021). Point of contact: investigating change in perception through a serious game for covid-19 preventive measures. *Proceedings of the acm on human-computer interaction* (pp. 1–19). ACM New York, NY, USA.
Hungerford, H. R., & Volk, T. L. (1990). Changing learner behavior through environmental education. *The Journal of Environmental Education, 21*(3), 8–21.
Huveneers, C., Meekan, M. G., Apps, K., Ferreira, L. C., Pannell, D., & Vianna, G. M. (2017). The economic value of shark-diving tourism in australia. *Reviews in Fish Biology and Fisheries, 27*, 665–680.
Jamovi Project (2024). *Jamovi: Free and open statistical software.* https://www.jamovi.org/. Accessed 18 Sep 2024
Mixamo (2024). *Mixamo: 3d animation platform.* https://www.mixamo.com/#/. Accessed 18 Sep 2024
Panagiotopoulou, L., Cía Gayarre, N., Scurati, G. W., Etzi, R., Massetti, G., Gallace, A., & Ferrise, F. (2021). Design of a serious game for children to raise awareness on plastic pollution and promoting pro-environmental behaviors. *Journal of Computing and Information Science in Engineering, 21*(6), Article 064502.
Papanastasiou, G., Drigas, A., Skianis, C., & Lytras, M. D. (2017). Serious games in k-12 education: Benefits and impacts on students with attention, memory and developmental disabilities. *Program, 51*(4), 424–440.
Piaget, J. (2000). Piaget's theory of cognitive development. *Childhood Cognitive Development: The Essential Readings, 2*(7), 33–47.
Ready Player Me (2024). *Ready player me.* https://readyplayer.me/pt. Accessed 30 Aug 2024
Rossano, V., Roselli, T. spsampsps Calvano, G. (2018). A serious game to promote environmental attitude. *Proceeedings of the smart education and e-learning* (pp. 48–55).
Shea, S., Slee, B. & O'Toole, M. (2022). *Supply and demand: the eu's role in the global shark trade*. International Fund for Animal Welfare.
Shiffman, D. (2022). *Why sharks matter: A deep dive with the world's most misunderstood predator*. JHU Press.
Shiffman, D., & Hammerschlag, N. (2016). Shark conservation and management policy: A review and primer for non-specialists. *Animal Conservation, 19*(5), 401–412.
Sketchfab (2024). *Sketchfab: 3d models online.* https://sketchfab.com/. (Accessed: 2024-08-30)
Streicher, A., spsampsps Smeddinck, J.D. (2016). Personalized and adaptive serious games. *Proceedings of the international gi-dagstuhl seminar on entertainment computing and serious games* (pp. 332–377).
Sudarmilah, E., Fadlilah, U., Supriyono, H., Irsyadi, F.Y.A., Nugroho, Y.S. & Fatmawati, A. (2018). A review: Is there any benefit in serious games? *Aip conference proceedings* (Vol. 1977).
Topelko, K. N., & Dearden, P. (2005). The shark watching industry and its potential contribution to shark conservation. *Journal of Ecotourism, 4*(2), 108–128.
Tsoi, K., Chan, S., Lee, Y., Ip, B., & Cheang, C. C. (2016). Shark conservation: An educational approach based on children's knowledge and perceptions toward sharks. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0163406
Unity Technologies (2024). *Unity: Real-time development platform.* https://unity.com/pt. Accessed: 27 Aug 2024
Veronica, R., & Calvano, G. (2020). Promoting sustainable behavior using serious games: Seadventure for ocean literacy. *IEEE Access, 8*, 196931–196939.
Warren, N., & Yoho, R. (2018). Misconceptions, sharks, and storybooks. *International Zoo Eucators Association Journal, 2018*, 9–12.
Zhonggen, Y. (2019). A meta-analysis of use of serious games in education over a decade. *International Journal of Computer Games Technology, 2019*(1), 4797032.

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