

A Serious Game Model of Marine Pollution for Public Awareness

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ABSTRACT

This study delves into the adverse effects of Marine pollution such as plastics and chemicals on the Marine environment and its wider ecological balance. Given the increasing impacts on global ecosystems and human health, the paper highlights the need to improve public understanding and engagement. The paper introduces an innovative approach through a serious game called Marine Conservation War, which aims to educate the public and motivate them in adopting positive environmental behavioural change. Using an ADDIE model integrated with an evaluation-driven design, the study followed a structured approach of methodology consisting of three main stages: Preparation stage and problem identification; design based on the analysis results; evaluation and iterative analysis. Initially, an extensive literature review and interviews helped identify key issues and potential solutions that formed the basis of the game's conceptual framework. Subsequently, games are designed and developed based on previous research's theoretical and empirical findings to ensure that games are both educational and engaging. A rigorous evaluation on usability and public awareness is conducted to determine the game's effectiveness in raising awareness and engagement in Marine conservation. The results confirmed that the game effectively communicated the seriousness of Marine pollution and may inspire players to take practical remedial measures. The pair-sample T-test used to assess changes in pre-post evaluation, showed significant improvements, confirming the impact of the game in usability and public awareness towards marine pollution. These findings highlight the potential of serious games as an environmental education tool, promoting an understanding, awareness and commitment to the conservation of Marine ecosystems.

Keywords: Marine pollution, public awareness, serious games, environmental education

INTRODUCTION

Games, a form of entertainment that combines art, technology, and interactivity, is more than just a pastime; it is a medium that can guide us through different virtual realities. From simple casual to complex strategy games, the world of games gives players the freedom to play, stimulating our creativity and desire to explore. As the game industry continues to evolve, serious games are emerging, combining the entertaining nature of games with deep thinking (Falk et al. 2023). Serious games emphasize themes such as education, social issues, and cultural inheritance and are designed to engage players interactively.

Serious play has received much attention and has been actively explored in recent years as a promising way to transform complex social ecosystems' cognitive and emotional aspects (Janssen et al. 2023). This innovative participatory approach has been widely welcomed in studying and analyzing global social and environmental issues (Speelman et al. 2019). Serious games have multiple uses, including but not limited to education, research, and intervention (Rodela, Ligtenberg & Bosma 2019).

Marine pollution is one of the significant environmental challenges facing the world, with severe impacts on Marine ecosystems and human societies (Mendenhall 2023). With increased human activity and industrialization, the oceans are threatened by various pollutants, such as plastic waste, chemicals, and oil spills. These pollutants cause severe damage to marine biodiversity, fisheries resources, and human health. Therefore, protecting the oceans from pollution has become particularly urgent (Schnurr et al. 2018).

In this context, this study aims to develop a serious game called "Marine Conservation War" that directly supports the achievement of Sustainable Development Goal 14 set by the United Nations - the conservation and sustainable use of the oceans and their resources and to raising public awareness and concern about Marine pollution with innovative game methods. The study hopes that the game will communicate the seriousness and impact of Marine pollution to players and inspire them to take positive action to protect the Marine environment. In serious games, players can experience their influence and gain a sense of accomplishment that translates into real-life positive action (Landrigan et al. 2020). Marine pollution is a severe problem because serious games have achieved good results in other areas, such as its vital role in raising public awareness of water resources, sustainable development, and other issues (Orduña Alegría, Schütze & Zipper 2020). A game-based approach stimulates creative, emotional tension, encourages participants to explore systemic behavior through virtual stress scenarios, and reveals new possibilities for action (van Noordwijk et al. 2020). Where traditional teaching methods cannot fully meet the learning needs of adults, experiential learning can help solve the difficulties faced by society through clever information transmission, and we can look forward to the critical application of serious games in the field of Marine pollution. This study makes three key contributions:

1. Developed a new educational model integrating serious game elements, software design principles, and environmental awareness to support marine conservation.
2. Enhanced game design by optimizing incentive mechanisms and employing modular and personalized strategies to improve educational value and player motivation.
3. Created the "Marine Conservation War" game, effectively combining educational content with engaging game mechanics to raise awareness about marine pollution.

This paper is organized as follows: literature review, methodology, result and analysis, discussion and conclusion. Section 2 explores the advantages of current serious games and their modelling methods through case studies and literature reviews, focusing on how these games motivate players and raise public awareness of marine pollution. Section 3 discuss the research methods, tools, and design procedures, combining the ADDIE and evaluation-driven design frameworks to guide game model construction. Section 4 presents examples of serious games developed with the Bakin Engine, highlighting development processes, usability evaluation, and performance analysis. Section 5 summarizes the research contributions, strengths and limitations, and future directions, particularly in enhancing public awareness of environmental protection and improving educational outcomes through game design.

LITERATURE REVIEW

Heizinga revealed the biological roots of play by tracing the animal world (Rose 2021). Taylor pointed out in "Primitive Culture" that games are a spontaneous activity for humans to release excess energy and are closely related to the development of creativity (Smith 2023). In addition to being a means of growth and development for children, play has also become a means of survival for adults to socialize. Since teaching aims to achieve people's full and free development, the concept of growth and development in happiness emphasized by the game has a natural combination with teaching. Therefore, it is theoretically reasonable to promote the development of gamification teaching.

Gamification introduces game ideas, mechanics, and elements into non-game contexts to help users solve problems and build themselves. They are widely used in product design, human resource development, marketing, and education and training. Gamification has performed well in education because of its compatibility with happy learning. Gamified learning as a creative, informal teaching method is among the top 10 innovative teaching trends (Parra-González et al. 2020). Many educational games have sprung up worldwide to support the realization of professional gamified teaching. Gamification teaching is a new teaching mode that has come into being after gamification entered the field of education. It aims to promote the development of educational activities in a student-centered direction by adopting gamification in the teaching process, effectively improving students' learning motivation and interest, and enhancing the learning effect. With the wide application of gamified design

in teaching, gamified teaching is no longer limited to simply introducing games into learning but integrating game elements, concepts, designs, and essence into teaching, thus promoting the reform of learning methods and educational innovation.

In the 1930s, Western countries began paying attention to the potential value of games in education (Tröhler 2023). They devoted themselves to studying how to stimulate learners' interest and learning motivation through game design and tried integrating games into the teaching curriculum. With time, in the late 1990s, foreign scholars gradually increased their attention to the design and development of educational games and put forward many corresponding methods and models (Zeng, Parks & Shang 2020).

Kiili (2005a) studied the combination of education and games from a new perspective and built an experiential learning game model from the game level, which made a breakthrough in integrating education methods and game design. Although this model has successfully developed some simple educational games, its limitation is that it only provides general design strategies and does not provide specific methods for effectively designing educational games. Ibrahim (2009) analyzed the experiential game model proposed by Kiili and the EFM educational game model proposed by Song Minju (Institute of Electrical and Electronics Engineers et al. 2009). She proposed a new educational game design model by integrating game design, education, and teaching content modeling. The model emphasizes usability, multimodality, fun, motivation, problem-solving, and syllabus matching, adding more knowledge and elements to educational design development models. Ibrahim also developed an educational game based on this model and evaluated its effectiveness, providing a reference for the effectiveness of educational game design (IEEE Computer Society & Institute of Electrical and Electronics Engineers 2019). However, the model focuses mainly on describing design elements and details and needs to give a detailed description of game design and teaching integration.

To solve the problem of duality in educational game design and development models, that is, focusing only on the game's internal components or the high-level. Based on activity theory, a conceptual model of educational games based on activity theory is developed (Fernández-Sánchez, González-Fernández & Acevedo-Borrega 2023). The model describes in detail how game elements are interconnected throughout the game and how these elements can help achieve the intended teaching goals (Carvalho et al. 2015). However, this model does not consider the social relations existing in the game, that is, the relationship between the subject and object of the game and the environment.

In addition, Clark (2016) explains the two-position framework of game-based learning and explores how games and education can be closely integrated. From the learning perspective of game strategy design, Kiili put forward different viewpoints on educational game design (Kiili 2005b). They constructed the CIMDELA (Content, guidance, mechanism, dynamics, participation, learning analysis) model (Herreevanooostendorp n.d.). This model's application shows that team-based design activities can expand learners' thinking in the game process, achieving effective learning.

International research on the design and development model of educational games has made remarkable progress, forming some reference design framework, which provides the basis for the continuous study of educational games in the future. However, no mature educational game design model with both educational significance and good playability has experienced the test of time or reality, which requires continuous efforts from developers. In this context, this study will mainly consider the current novel model-building method that can be combined with the analyzed model optimization method. This modeling method combines the interview method and the literature review method (Mokhtar, Ismail & Muda 2019).

American scholar Roth put forward the term environmental literacy, regarded as a synonym for environmental awareness (Guerrero & Sjöström 2024). Environmental awareness is a collection of advanced thoughts on the relationship between humans and the earth. On the other hand, regards environmental awareness as a new value concept for the harmonious development of man and nature, including various ideological forms such as social thought, emotion, and perception. According to Roth's definition, it further divides environmental awareness into 4 dimensions: environmental protection

concern, environmental, economic awareness, and environmental ethics awareness, fully interpreting the relationship between man and nature. Environmental awareness synthesizes people's understanding of the environment and environmental protection awareness (Yang et al. 2022). In modern development, environmental awareness is interpreted as adults' awareness of the environment and environmental protection. It includes adjusting people's economic activities and social behaviors to protect the environment and their participation and consciousness in practical activities to maintain the relationship between man and nature. Therefore, from the perspective of the development process of environmental awareness in The Times, today's environmental awareness is the sum of people's thoughts and behaviors on nature and nature protection.

TABLE 1. Different Countries Treat the Definition of Public Awareness.

Country	Meaning	Elements	Evaluate Method
China (Kuai et al. 2022)	It is a multi-dimensional construct with emotional, cognitive, and willingness aspects.	Environmental concerns, environmental attitudes, environmental knowledge, and behavioral intentions	Questionnaire
India (Dowarah, Duarah & Devipriya 2022)	The sum of knowledge, understanding of environmental issues, and positive commitment to solving them	Fundamental beliefs, facts, scientific knowledge of environmental issues, and a commitment to solving them.	Questionnaire
Malaysia (Mei, Wai & Ahamad 2016)	Emotional responses, attitudes, and practical, sustainable practices of individuals and societies to environmental issues.	Sustainability-conscious emotions, attitudes, and practices.	Questionnaire

Additionally, we analyzed a total of 20 previous studies on serious games over the last five years (2019-2024). The 20 studies cover health care, education, and the environment. There were seven studies in the medical field, six in education, and seven in the environmental field. Through the analysis of these 20 studies, a total of 22 elements of serious play for training were identified. Table 2 lists the statistical elements of serious play.

TABLE 2. Elements from Serious Games Nowadays.

Bil	Author	Title	Domain	Game Elements
1	Fox et al. (2020)	Using a serious game to communicate risk and minimize psychological distance regarding environmental pollution	Environment	Interactive, Immersive, Involvement, Rules, Storyline, Reward, Players Objective, Game outcome, Enjoyment, A sense of control
2	van Wijk et al. (2024)	A serious game approach for lake modeling and management: The EscapeBLOOM	Environment	Interactive, Immersive, Challenges, Rules, Involvement, Storyline, Reward, Players Objective, Game outcome, Enjoyment
3	Agusdinata et al. (2024)	Effectiveness of conservation messages to reduce households' GHG emissions: A serious-gaming experiment	Environment	Scenario, Interactive, Rules, Involvement, Feedback, Players Objective, Game outcome, Enjoyment, Goal, Game mechanics
4	Sillanpää, Eichhorn & Juhola (2024)	Decreasing psychological distance to climate adaptation through serious gaming: Minions of Disruptions	Environment	Interactive, Challenges, Rules, Involvement, Storyline, Reward, Players Objective, Game outcome, Enjoyment
5	Khoury et al. (2023)	NEXTGEN: A serious game showcasing circular economy in the urban water cycle	Environment	Interactive, Challenges, Rules, Involvement, Storyline, Reward, Players Objective, Game outcome, Enjoyment
6	Barcena-Vazquez et al. (2023)	Designing and evaluating Reto Global, a serious video game for supporting global warming awareness	Environment	Interactive, Storyline, Goal, Game mechanics, Reward, Players Objective, Game outcome, Enjoyment, Game Procedures, Resources
7	Gürer, Surer & Erkayaoğlu (2023)	MINING-VIRTUAL: A comprehensive virtual reality-based serious game for occupational health and safety training in underground mines	Education	Interactive, Immersive, Game mechanics, Feedback, Rules, Scenario, Challenges, Involvement, Game outcome, Enjoyment
8	Gómez-	A smartphone-based serious game for	Medical	Feedback, Interactive, Game mechanics,

	Cambronero et al. (2023)	depressive symptoms: Protocol for a pilot randomized controlled trial		Game Procedures, Resources, Conflict, Game Play, Playability, Involvement
9	Yrjo et al. (2024)	Enhancing risk assessment skills in hazardous environments: Priming with a serious game approach	Education	Interactive, Game mechanics, Game Procedures, Resources, Conflict, Game Play, Playability, Involvement, Focus attention
10	Baranyi et al. (2023)	Rehafox – A therapeutical approach to developing a serious game to support the rehabilitation of stroke patients using a leap motion controller	Medical	Interactive, Immersive, Game mechanics, player objective, Game outcome, Goal, Gameplay, Interaction Modes, Playability, A sense of control
11	Lattera et al. (2023)	MARCHI: A serious game for participatory governance of ecosystem services in multiple-use protected areas	Environment	Interactive, Goal, Game mechanics, Players Objective, Feedback, Rules, Conflict, Game Play, Involvement, Storyline
12	Hart, Halak & Sassone (2022)	CIST: A Serious Game for Hardware Supply Chain	Education	Interactive, Challenges, Rules, Involvement, Players Objective, Game outcome, Goal, Game mechanics, Game Procedures, Resources, Conflict, Game Play, Interaction Modes.
13	Ryschawy et al. (2022)	A participatory approach based on the serious game Dynamix to co-design scenarios of crop-livestock integration among farms	Education	Involvement, Game Procedures, Interaction Modes, Focus attention, Playability
14	Lovreglio et al. (2022)	Prototyping and testing a virtual reality counterterrorism serious game for active shooting	Education	Interactive, Immersive, Storyline, Game mechanics, Players Objective, Involvement, Rules, Feedback, Conflict
15	Daylamani-Zad, Spyridonis & Al-Khafaaji (2022)	A framework and serious game for decision-making in stressful situations; a fire evacuation scenario	Medical	Immersive, Interactive, Goal, Game mechanics, Challenges, Rules, Feedback, Involvement, Storyline
16	Palee et al. (2020)	Serious Game for Teaching Undergraduate Medical Students in Cleft Lip and Palate Treatment Protocol	Medical	Scenario, Feedback, Interactive, Challenges, Rules, Players Objective, Game outcome, Goal, Game mechanics, Involvement, Storyline
17	Khaleghi, Aghaei & Behnamghader (2022)	Developing two game-based interventions for dyslexia therapeutic interventions using gamification and serious games approaches entertainment computing journal.	Education	Interactive, Immersive, Feedback, Players Objective, Rules, Goal, Game mechanics, Involvement, Enjoyment, Storyline
18	Kristoffersen et al. (2020)	Serious gaming to generate separated and consistent EMG patterns in pattern-recognition prosthesis control	Medical	Interactive, Feedback, Game mechanics, Involvement, Goal, Playability, Focus attention
19	Martins, Carvalho & Soares (2020)	Physioland – A serious game for physical rehabilitation of patients with neurological diseases	Medical	Interactive, Immersive, Challenges, Feedback, Game mechanics, Player's Objective, Game outcome, Goal, Storyline
20	Tsopra et al. (2020)	AntibioGame®: A serious game for teaching medical students about antibiotic use	Medical	Interactive, Immersive, Challenges, Feedback, Game mechanics, Player's Objective, Game outcome, Goal, Storyline

METHODOLOGY

Focusing on the integration between the scientific method and game development, the research methodology integrates the five stages of analysis, design, development, implementation, and evaluation in the ADDIE model with the three main stages of pre-planning, design, and evaluation in Evaluation-Driven design. In order to simulate the entire serious game design and evaluation process, the methodology for this study is divided into three stages:

1. Preparation stage and problem identification: The game project begins at the preparatory stage with case studies to discover and analyze the direction of game optimization and the software design principles applied behind it. Through literature review and interview survey, find the solution to the problem and the development direction of the game. This stage also includes consideration of the game environment and analysis of traditional methods to provide a basis for determining the goals of the game. In addition, this stage also gathers the serious game elements needed to build a conceptual model of the game, defines the content of public awareness and Marine pollution covered in the game, and ways to survey public awareness. This phase combines the analysis phase of ADDIE with the initial preparation of an evaluation-driven design.

2. Design based on the analysis results: The underlying theory identified through the preparation phase and problem identification, including the cause, mechanism, process, and modifiable variables of the problem, lays the foundation for solving the problem through the game. Once the problem and goals are identified, the information gathered is used to build a conceptual model and develop the game. This phase incorporates the evaluation-driven game design into the design and development of ADDIE.

3. Evaluation and iterative analysis: Evaluation is an integral part of the entire process and should be considered at the beginning of the design. Evaluation and design are interdependent, focusing on the intended goals of the game. The framework encourages the development of serious games following the standard scientific research procedures. Usability evaluation of developed games can guide the optimization of future games, including developing strengths and fixing weaknesses. This phase enhances the purpose and effectiveness of evaluation in ADDIE by introducing more detailed evaluation steps in evaluation-driven design.

The architecture of our proposed method is shown in Figure 1.

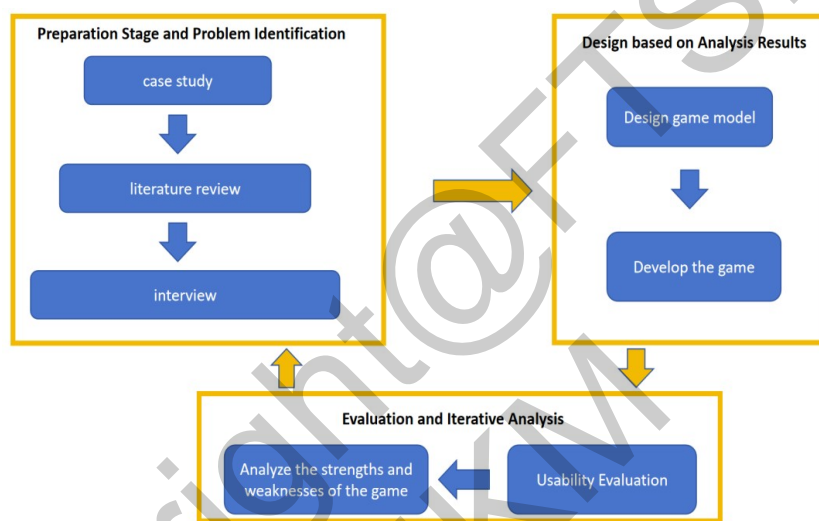


FIGURE 1. The Research Methodology.

Preparation Stage and Problem Identification

Case Analysis Phase

Doing case studies of existing games before developing them is standard practice. The characteristics of case analysis in game development are reflected in in-depth understanding, problem identification, experience reference, industry trends, and inspiration. By carefully reviewing and studying existing games, development teams can comprehensively understand the design, features, and user experience of different games to identify their shortcomings. This approach focuses on learning from specific cases. Through in-depth analysis of all aspects of the game, the development team is more familiar with the dynamics of the game industry and the direction of innovation.

These three cases allow us to observe the role and effects of serious games in education and social change. These games promote knowledge dissemination and behavior change in unique ways, demonstrating the importance and potential of gamification strategies in modern education and social engagement. This comprehensive analysis helps us identify the optimization direction and provides valuable insights and references for future innovation in game development and related fields.

TABLE 3. Game Features and Referential Optimization Direction.

Game Name	Game Feature	Optimisation Direction
Bleached Az (Bleached Az 2024)	Unlock exclusive episodes in the game, and participation in the tree planting program allows players to get involved in social affairs.	The design of incentive mechanisms

Working with water (Working with Water 2024)	Players face different challenges and must develop a comprehensive strategy for dealing with them.	Game strategy integration
Coronaquest (CoronaQuest 2024)	Teach children about pandemics in a lively and fun way through character cards and interactive teaching.	Innovative forms of gamified teaching

Literature Review Phase

At this phase, this study will conduct a literature review on the solutions to the problems existing in serious games as obtained from the case analysis to seek solutions and perform a corresponding literature search on games' content on raising public awareness of Marine pollution. At the same time, this phase will also collect the elements of serious games that currently drive players to play to guide the production of game models.

TABLE 4. Design Principles Corresponding to Game Characteristics in Different Periods.

Stage	Features	Design Principles
Early stage (1980s - early 1990s)	The game design is relatively simple and technically limited. Focus on ease of use and usability.	Simplicity and usability; Modularity and maintainability
Middle stage (mid 90s - late 2000s)	As technology advances, game design becomes more complex. Interdisciplinary integration with emphasis on interactivity and user experience.	Interactivity and user experience; Scalability
Late stage (late 2010s - present)	More personalized game incentives and broader application of technology. Gamified teaching becomes part of the education system, focusing on fostering innovation and social responsibility.	Personalization and big data analytics; Sustainability and social responsibility

Through a comprehensive analysis of the evolution of games in their historical evolution, the following four categories of optimization strategies can be summarised to promote a more integrated educational experience. In software design, these optimization strategies can be combined with actual design principles to guide the design better. The specific design principles correspond to Table 5.

TABLE 5. Optimization Strategy Corresponding Design Principles.

Category	Design Principles
Optimize the design of incentive mechanism	User experience design principles: Usability and appeal. Application principles of educational theory: Cognitive theory and Constructivism theory. Software engineering design principles: Maintainability and extensibility
Game strategy integration	User experience design principles: Usability and appeal. System architecture design principles: modular design and personalized design. Application principles of educational theory: Cognitive theory and Constructivism theory
Innovative gamification teaching form	Principles of user experience design: Usability and engagement, especially social design. System architecture design principles: modular design and personalized design. Application principles of educational theory: Cognitive theory and Constructivism theory
Enhance the balance of the education function	User experience design principle: Usability. Software engineering design principles: Maintainability and extensibility. Principles of Educational Theory Application: The concept of social design and integrated development

Content Validation Phase

The purpose of this phase is to fill possible content gaps while at the same time searching for and repairing flaws and defects that may exist in the first stages to ensure better that serious game development can achieve its design objectives. This study's content validation method is an interview. This approach will enable this study to gain insights and data from experts to meet the research objectives better. Through interviews, this study will have the opportunity to understand the public's perceptions, attitudes, and aspirations towards enriching game production from an expert perspective.

The interviews indicate that serious game design, environmental awareness, and public behavior may all be affected by gamification. The respondents recommended including gaming components in regular tasks to inspire people to take ecological action. Success stories demonstrate the need to have both interesting gameplay and instructive material. When creating serious games, player interest and scientific accuracy must be balanced. These observations offer doable approaches for serious game creation and design that can increase public understanding of environmental concerns and encourage sustainable behavior change.

Simultaneously, gamification can alter public perceptions and behavior regarding marine pollution by boosting incentive systems and attraction. Fun gameplay, community involvement, and integrated educational content should all be included in successful eco-friendly games, guaranteeing scientific accuracy and sustaining player interest over time. Creating serious games is difficult because of the medium information delivery and dynamic gameplay mechanics, which call for a compelling story and user-friendly game design.

Design Based on the Analysis Results

This stage includes the collection of game model elements, the determination of optimization strategies, and the construction of game models, to raise public awareness of Marine pollution and promote sustainable development awareness through comprehensive analysis and careful design. First, through literature reviews and case studies, the researchers identified key elements that motivate players to engage and increase environmental awareness, such as environmental awareness, environmental values, and engagement. These elements are seen as core factors directly related to behavioral change. Then, based on the six game elements discussed in Chapter 2, the application of these elements to game design is clarified. In the optimization strategy phase, combining the characteristics of serious games and tower defense games, special emphasis is placed on design principles such as simplicity, usability, modularity, maintainability, interactivity, and user experience to ensure that the game achieves superior performance and user satisfaction in multiple dimensions. This strategy reinforces the educational aspect of the game, ensuring its appeal and sustaining player interest. In the game model-building phase, through literature research and expert interviews, the design direction of the game content was determined, key information about Marine pollution was accurately conveyed, and game mechanisms interacting with real-world ecosystems were designed to deepen players' understanding of the impact of pollution. These strategies and systematic design methods lay a solid foundation for creating a game that effectively raises environmental awareness and encourages public participation in environmental activities, ensuring the game's theoretical and practical success, as well as its social responsibility and educational effectiveness.

The Elements Collection of Game Model

This study focuses on the elements of environmental awareness, values, and participation to motivate players towards positive ecological behaviors in real life through serious games. By increasing environmental awareness, players can better understand the impact of environmental issues on their lives, inspiring motivation and willingness to act. Shaping environmental values encourages players to prioritize environmental protection and sustainable development. Enhancing the sense of participation allows players to simulate and practice environmental behaviors in the game, translating positive participation into actual actions that promote sustainable development. Ethics and the rule of law, while important, are not the focus due to their more indirect and long-term impacts. Serious games aim to achieve behavior change through short-term interactions, making emotional experience and immersion key factors in developing positive environmental attitudes and behavioral intentions.

The game mechanics incorporate conceptual models and characteristics of tower defense games to enhance strategic thinking and participation. Players use island resources to place defense towers against human pollutants, offering strategic options and raising environmental awareness through interactive mechanisms. Key game elements include game outcomes (e.g., ocean cleanup), clear objectives (e.g., protecting marine ecosystems), an engaging storyline set in a fictional polluted world, interactive mechanisms (e.g., building defense towers), and rules emphasizing real-world ecological impacts. These

elements collectively train players in strategic thinking and environmental awareness, making the game both entertaining and educational.

TABLE 6. Comparison of Game Elements, Measures, and Advantages.

Design Element	Measures	Advantages
Game Outcomes	Design game outcomes as ocean cleanup, allowing players to experience the positive environmental impact of their efforts directly.	Creates a sense of urgency for environmental goals and reflects environmental achievements through game outcomes.
Player Objectives	Set clear objectives such as protecting marine ecosystems from pollution, cleaning specific areas, or raising public awareness.	It provides a clear sense of direction, gradually achieves overall goals, and increases the game's depth and challenge.
Storyline	Set in a fictional world threatened by pollution, it introduces deep characters, missions, and plots.	It enhances the game's appeal and immersion, allowing players to understand the impact of marine pollution more comprehensively.
Engagement	Provide rich interactive mechanisms, such as building defense towers and executing cleanup tasks.	It enhances players' sense of participation and responsibility, allowing them to experience their contributions to the game through actions.
Rules	Set clear goals and tasks, emphasizing the impact of real-world rules on ecosystems.	It helps players understand the urgency of environmental issues and regulates player behavior.
Interactivity	Increase strategic choices through interactive mechanisms like selecting defense towers and cleaning ocean pollution.	Enhances the game's fun and active engagement, improving the depth of the gaming experience.

Optimization strategies focus on simplicity, usability, modularity, maintainability, interactivity, and user experience to ensure excellent performance and user satisfaction. Simplifying operations and interfaces increases participation and educational effectiveness. Modularity and maintainability support system stability and ongoing content updates. Enhancing interactivity and user experience improves immersion and educational impact. Emphasizing sustainability and social responsibility guides players towards positive environmental behaviors, fostering social responsibility and aligning with educational principles. This targeted approach maximizes educational value and user engagement, ensuring that the game effectively addresses Marine pollution while providing an entertaining experience.

TABLE 7. Comparison of Design Principles, Measures, and Advantages.

Design Principle	Measures	Advantages
Simplicity and Usability	Simplify game operations and interface to facilitate user onboarding and improve usability.	Increases user participation, thereby enhancing the game's impact and educational effectiveness.
Modularity and Maintainability	Adopt modular design principles to ensure system stability while making the game more accessible for expansion and update.	Helps continuously provide new educational content and challenges to users while simplifying game maintenance and management.
Interactivity and User Experience	Integrate insights from case studies to adjust game design elements, such as interface layout and interaction mechanisms, to enhance game appeal and educational impact.	It enhances player immersion, thereby increasing the likelihood of learning from the game and aligning with educational theories, emphasizing active engagement.
Sustainability and Social Responsibility	Incorporate social design concepts into the game and emphasize guiding players towards positive environmental behaviors.	It has a deeper impact on fostering social responsibility and sustainability, aligning with educational principles that stress social participation and accountability.

Game Model Building

The model design of the game will focus on the presentation and interactivity of educational elements. This study identifies the main aspects of game design through a literature review. At the same time, the game optimization strategies collected during the analysis phase and the game content required to raise public awareness of Marine pollution will guide the information that should be included in the game to

design serious games that help players understand the Marine pollution problem. In addition, the missions and challenges will be designed to interact with real-world ecosystems, giving players a better understanding of the impact of pollution on Marine life and the environment.

Based on the factors that can improve players' internal motivation and the methods of game optimization collected in the literature review, this study analyzed the public awareness represented by game elements according to literature, combined with the suggestions given by experts in the interview and built the following game conceptual model of game elements - design principles - public awareness as shown in Figure 2. In addition, the information directly derived from human Marine pollution collected through literature review and interviews will be added to the game in the form of game content, such as game scene, game background design, enemy design, and so on.

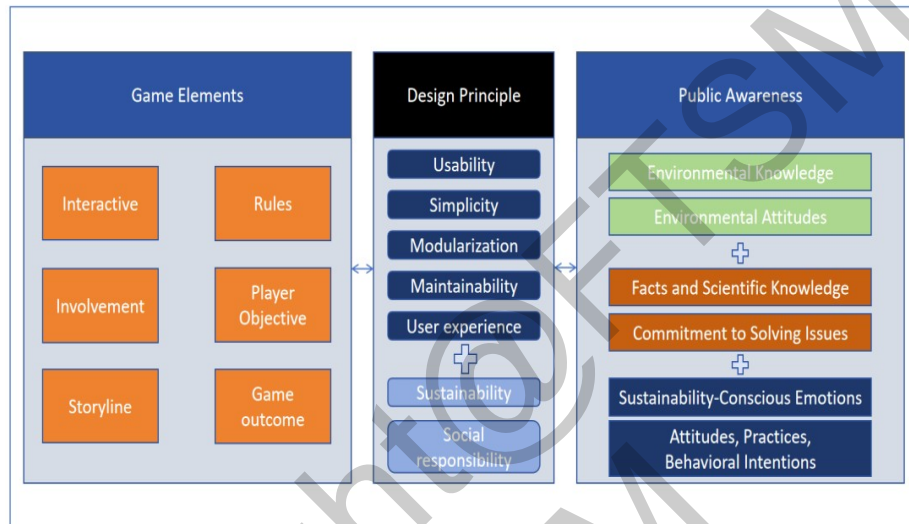


FIGURE 2. Model of the Game Design.

Game Development

Based on the game's concept model established, the game is developed by combining the characteristics of the tower defense game and the collected game optimization strategy, and visualizing the game flow. Figure 3 is the game's storyboard, through which each interface's content design is more intuitively displayed. The specific content for the game developed is shown in Figure 4, showing the basic flow from entering to exiting the game.

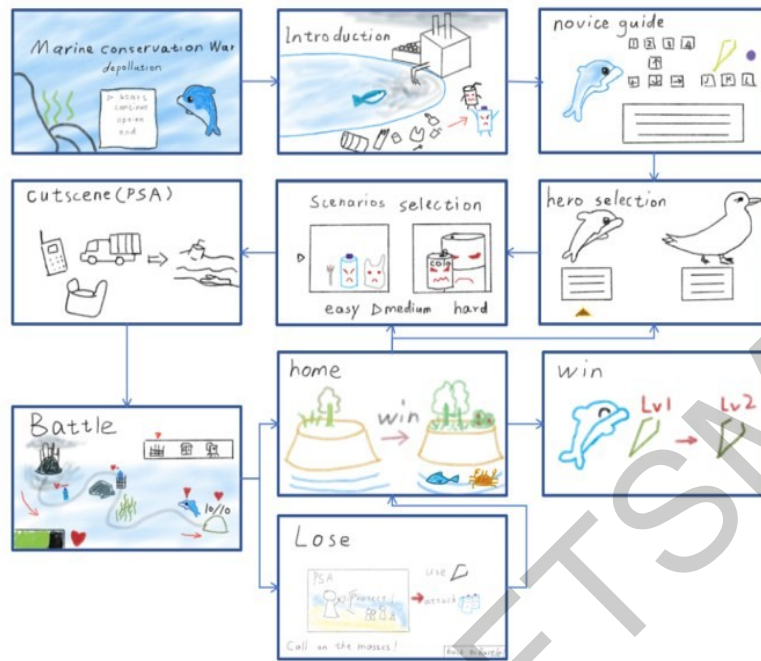


FIGURE 3. Game Storyboard.

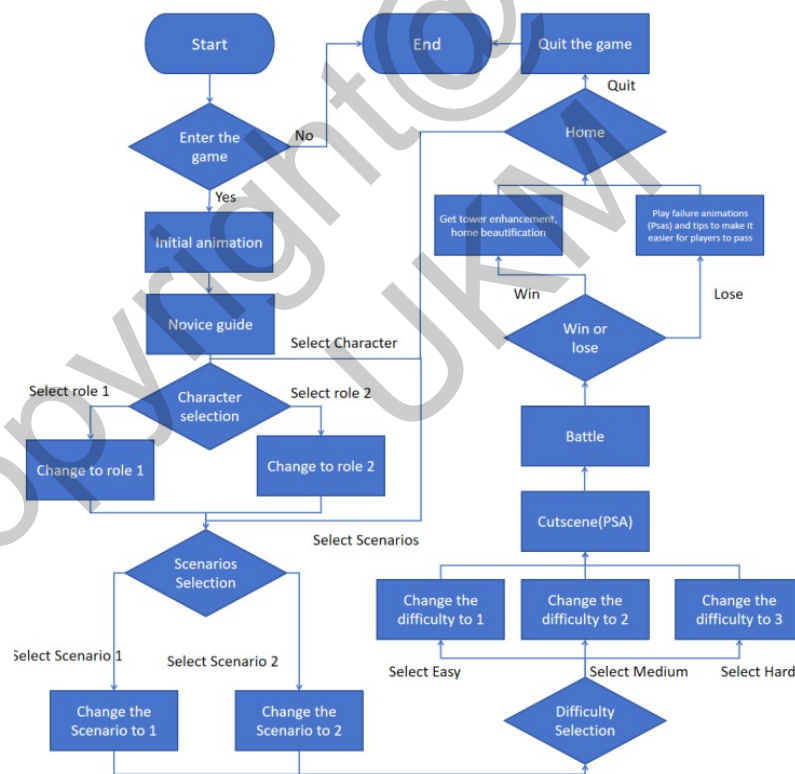


FIGURE 4. Game Flow Chart.

Based on feedback from the usability literature, the construction of the prototype program will follow several requirements, including fact-based, modular, layered, optimized, user-oriented, implementable, context-based, and easy to evaluate. In this stage, the research will combine the game model established in Chapter 3 and the suggestions obtained from the expert interviews and follow the usability principles of learnability, memorability, efficiency, and user satisfaction to develop the game prototype. The prototype has two main scenes, representing the contaminated Pacific and Atlantic. The names of the scenes in the prototype were adapted from the real Pacific and Atlantic Oceans to suit the lives of the

target audience and the types of pollution. In each scenario, users face different common domestic pollution for targeted defense. The scenario selection and two scenarios are shown in Figures 5, 6, and 7.



FIGURE 5. Scene Selection for a Prototype Game.



FIGURE 6. Scene Construction of Placific in the Game.



FIGURE 7. Scene Construction of Tratlantic in the Game.

Most importantly, there are multiple incentives. After completing the scene, the serious prototype transports the user to their home, giving them upgrade points to upgrade their weapons and items. The home will be beautified and enhanced when the user completes the two scenes, which are easy, medium, and hard difficulty. In addition, users can view the number of times they have cleared the customs in their homes and receive slogan incentives. According to expert advice, users will receive different environmental advice depending on their chosen role. Among them, the role of the seagull is regarded as a symbol of the rich, and the ecological protection suggestions received are more energy-saving and emission-reduction scientific and technological suggestions. In contrast, the tips the dolphin receives as a symbol of the civilian are closer to daily life.

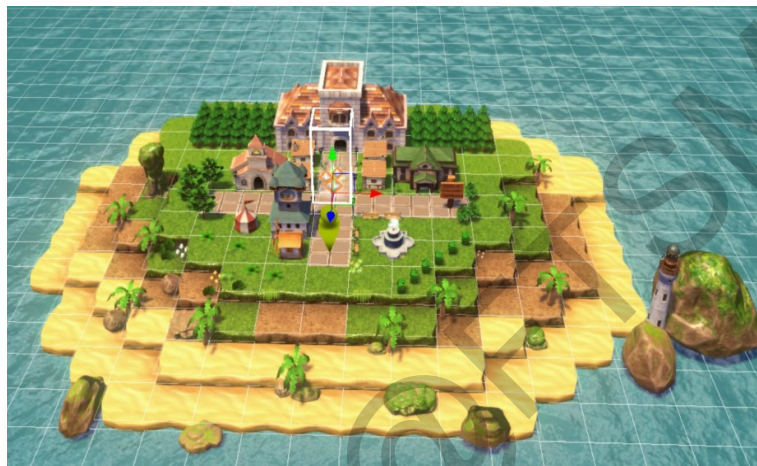


FIGURE 8. In-Game Home Building.

Through this design, rewarding upgrade points and allowing players to upgrade weapons and items increases the player's sense of accomplishment and enjoyment of the game, motivating them to continue participating. After each two scene, the beautification and enhancement of the home provide the player with visual and functional rewards that make the game more engaging. Players can view their level records in their homes, get slogans to motivate them, and collect different environmental advice depending on the character. This can increase the player's sense of pride and belonging, motivating them to complete more challenges. This mechanism of gradually upgrading and beautifying homes and the addition of collecting elements encourages players to invest in the game for a long time, constantly improving their achievements and the state of their homes while strengthening the educational effect of the game in the process of entertainment, helping players to understand better and pay attention to the problem of Marine pollution. Through the advice of expert interviews, we ensure that the game design is not only educational but also provides a rich user experience and promotes environmental protection awareness.

Evaluation and Iterative Analysis

In this study, the third stage is game evaluation, which seeks to confirm the software usability of the game prototype and its impact on increasing public awareness. To comprehend how a game behaves and affects real life, one must evaluate its framing components, which include information and content, game mechanics, narrative and story, aesthetics, and graphics. The main topics of this phase are how these components interact and how that affects the game's goals.

This evaluation phase has two goals: first, assess how easily users can understand and use the game by determining the user interface and interaction design; second, assess how well the game can increase public awareness of marine pollution and promote environmental action through the game evaluation. This covers information learned during the game and shifts in attitudes and behavioral goals.

The game evaluation section will invite 30 public users of different ages and genders to try out the developed prototype and complete questionnaires before and after the trial to conduct a detailed usability evaluation. The actual user experience and feedback from the public are of great reference value in

evaluating the usability of the game prototype. Input from public users will reveal the prototype's advantages and disadvantages in practical use and its practical effect in raising public environmental awareness.

The evaluation process involved recruiting participants and obtaining their consent, followed by a trial game, after which participants were asked to fill out questionnaires to provide feedback. The collected data will be analyzed to identify problems, trends, and optimization directions. Ultimately, based on this data and feedback, the research team will develop strategies to improve the overall quality of the game and its practical application value. Specifically, the evaluation process will be carried out through the following steps in Table 8.

TABLE 8. Game Evaluation Process.

Step	Description
Recruitment and Consent	Invite your target audience to play evaluation and obtain their informed consent. The audience is mainly the general public, ensuring they have a specific representation and diversity.
Game Experience	After filling out the pre-completion questionnaire, participants will play the game independently. During the evaluation, they will be free to explore the game content and features to experience the full game prototype content as much as possible.
Questionnaire Filling	Participants filled in questionnaires before and after the game experience. The pre-evaluation questionnaire was designed to obtain participants' initial cognition and attitude towards marine pollution, and the post-evaluation questionnaire was used to assess the impact of game experience on their cognition and attitude.
Data Collection and Analysis	Collect all questionnaire data and conduct statistical analysis to evaluate the game's usability and educational effect. The study includes comparing pre-and post-evaluation results and qualitatively analyzing user feedback.
Report Preparation	Based on the data analysis results, prepare a detailed evaluation report, summarise the advantages and disadvantages of the game, and put forward suggestions for improvement.

Through the above steps, this study will be able to comprehensively evaluate the usability of the game prototype and its ability to promote public environmental awareness and provide a scientific basis for further development and optimization of the game.

RESULTS AND DISCUSSION

Usability evaluation is done to improve the user experience and is a crucial evaluation tool. By observing how users interact with the product, we can uncover issues in the design that may have been overlooked, such as an interface that is difficult to navigate or features that could be more intuitive. Early usability evaluation can help us promptly identify and resolve these issues, saving long-term maintenance and trial-and-error costs (Baharuddin, Singh & Razali 2013).

By providing evaluations for a product to verify that it meets user needs, usability evaluation can significantly increase user satisfaction and loyalty, enhancing the product's competitiveness in the market. In addition, usability evaluation enables custom design for specific user groups, ensuring the product is accessible and easy for all users. More importantly, usability evaluation provides insights based on actual user data, helping teams make decisions based on data rather than just relying on intuition. In summary, usability evaluation can improve the overall quality of optimization strategies and lay a solid foundation for creating a more engaging and practical user experience (Aziz et al. 2021).

Therefore, at this stage, this study will first distribute questionnaires to the subjects to collect their basic information and the level of public environmental awareness, which mainly involves ecological awareness, environmental values, and participatory views. This study will use this level of understanding to compare with the level of public environmental awareness after playing to study the efficiency of the game prototype in promoting public awareness. The study also evaluated several usability aspects in a questionnaire to verify the game prototype's feasibility thoroughly (Othman et al. 2022).

Participant Groups Introduction

For the basic information of the participants, descriptive statistical analysis was conducted based on the completed questionnaire. The age distribution is between 21 and 45 years old, with an average age of 31.2 years, and the sex ratio is 50% male and 50% female. Regarding learnability, most participants said that after play evaluation, they could quickly learn the game's basic operations. In terms of memory, participants generally reported being able to recall the game actions soon after some time. The data shows that the game's interface and functional design are rated highly in efficiency and satisfaction. However, there is room for improvement, especially in making the game more intuitive and easy to guide.

Regarding environmental awareness, participants' awareness of Marine pollution increased significantly before and after the game. After the match, more participants said they had a deeper understanding and heightened concern about the consequences of Marine pollution. At the same time, the game has effectively increased participants' willingness to participate in environmental activities. More participants said they were willing to participate in ocean cleaning and other ecological activities after the evaluation than before the game was evaluated.

Interpretation of Likert Scale Results

This study will further examine the gathered data using Mean Score Interpretation and T-test in the data analysis. Interpreting mean scores and using the Likert scale guarantee the scientific method and provide good comparability and wide applicability of the research findings. In the social sciences and psychology, the T-test is a well-known statistical technique used to help researchers ascertain whether differences between two data sets are more than chance (Vankelecom, Loeys & Moerkerke 2024). Small sample sizes can thus be used for this test, which works especially well in research where test conditions and sample size are controlled. Researchers can further enhance the dependability of the findings of the gathered evaluation data by using the T-test to determine whether changes before and after the game are statistically significant.

TABLE 9. Mean Score Interpretation Standard.

Range	Interpretation
4.21-5.00	Very high
3.41-4.20	High
2.61-3.40	Medium
1.81-2.60	Low
1.00-1.80	Very Low

Note: Data adapted from Hadiyanto et al. (2021).

Using this standard, researchers will statistically examine every Likert scale question item in detail, including mean score and standard difference. Table 9 provides the Mean Score Interpretation applied in this study to assess the 5-point Likert scale to illustrate the importance of these data changes more precisely. These scoring criteria enable us to better understand participant feedback and behavior by allowing us to extract richer and more illuminating qualitative information from quantitative data.

Usability Evaluation Results Analysis

After completing two questionnaires, the researchers collected and collated the data. In this usability evaluation, 32 questionnaires were issued, all of which were recovered, 30 of which were filled in. The questionnaire recovery rate was 100%, and the completion rate was 93.75%. The high participation rate and the high completion rate of the questionnaire ensured the adequacy and validity of the data collection, providing a solid foundation for subsequent data analysis.

By comparing the questionnaire results before and after the evaluation, we can see significant improvements in various dimensions. These dimensions include learning ability, memory, efficiency, satisfaction, environmental awareness, values, and engagement.

TABLE 10. Learnability Result.

Question	Mean Score (Pre)	Mean Score (Post)	Change
Q1	3.07	4.03	+0.96
Q2	2.97	3.93	+0.96
Q3	3.13	4.07	+0.94
Q1-Q3	3.06	4.01	+0.95

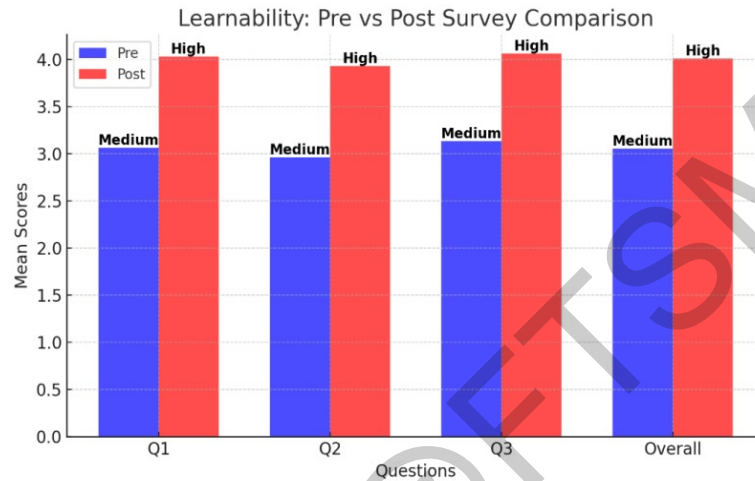


FIGURE 9. Learnability Result Bar Chart.

Regarding learnability, the average score increased from 3.03 before the evaluation to 4.01 after, reflecting that the game design effectively helps players quickly understand and adapt to the game. As an Educational tool, it is essential since it improves players' motivation and capacity for learning.

TABLE 11. Memorability Result.

Question	Average Score (Pre)	Average Score (Post)	Change
Q4	2.70	3.67	+0.97
Q5	3.03	3.97	+0.94
Q4-Q5	2.87	3.81	+0.95

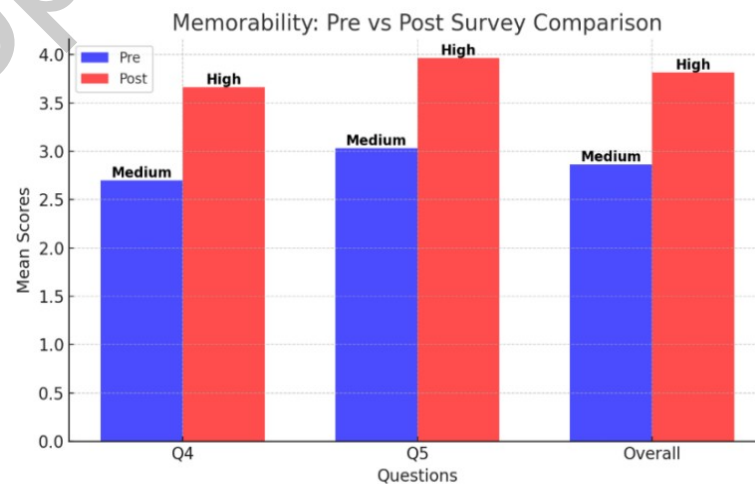


FIGURE 10. Memorability Result Bar Chart.

According to memory tests, players perform better when recalling game details and actions during non-game time. This suggests that games are excellent at helping players remember the material over time, which is crucial to ensuring that educational content has a lasting effect. The average score on the

memory test after the game increased from 2.87 to 3.81, demonstrating the effectiveness of the game in enhancing memory persistence.

TABLE 12. Efficiency Result.

Question	Mean Score (Pre)	Mean Score (Post)	Change
Q6	2.73	3.77	+1.04
Q7	3.00	3.90	+0.90
Q8	2.73	3.67	+0.96
Q6-Q8	2.82	3.78	+0.96

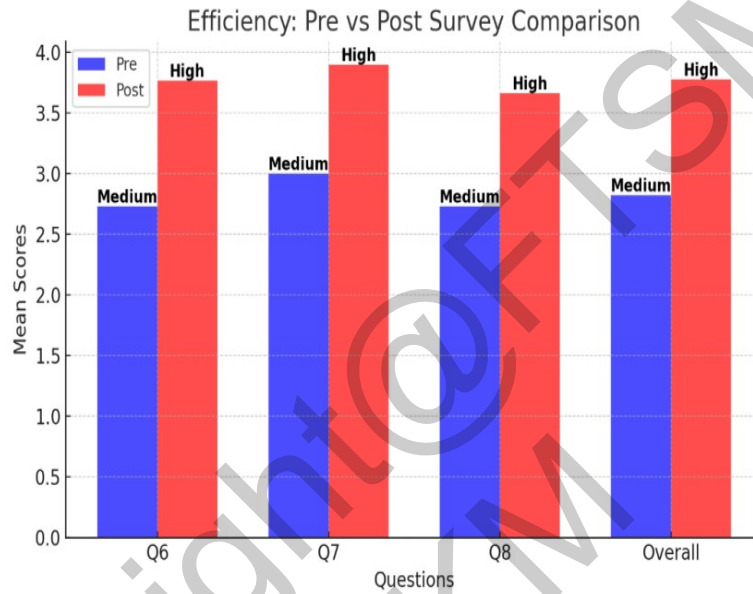


FIGURE 11. Efficiency Result Bar Chart.

Players report that the interaction with the game is more fluid and intuitive, which indicates that the interface and game mechanics have been optimized so that players can complete tasks faster. The efficiency score increased from 2.82 to 3.78, showing significant progress in improving operational efficiency and the speed at which players complete tasks.

TABLE 13. Satisfaction Result.

Question	Mean Score (Pre)	Mean Score (Post)	Change
Q9	3.03	3.53	+0.50
Q10	2.73	3.03	+0.30
Q11	3.00	3.13	+0.13
Q9-Q11	2.92	3.23	+0.31

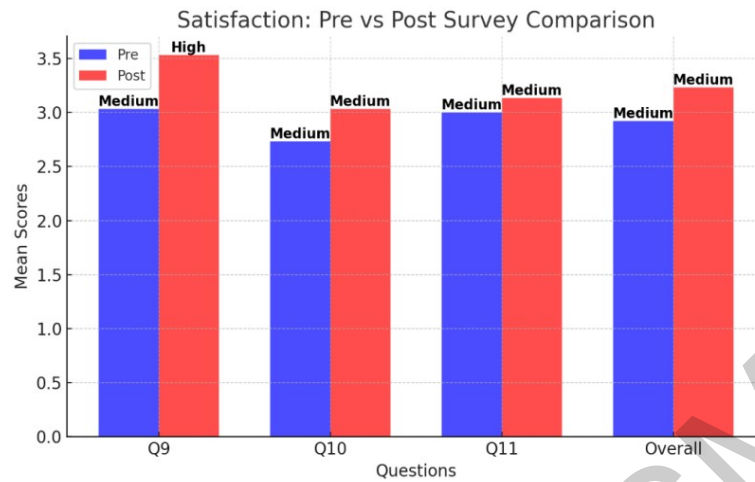


FIGURE 12. Satisfaction Result Bar Chart.

Despite the increase in satisfaction, the change in scores also shows that there is still room for improvement. The score of satisfaction before and after the game increased from 2.92 to 3.23, although it was improved, the changes in individual satisfaction indicated the need to customize the game to suit different player preferences, effectively increasing player interest and enjoyment.

Public Awareness Evaluation Results Analysis

TABLE 14. Environmental Awareness Result.

Question	Mean Score (Pre)	Mean Score (Post)	Change
Q12	2.83	3.27	+0.44
Q13	2.83	3.27	+0.44
Q14	3.13	3.47	+0.34
Q15	3.17	3.53	+0.36
Q12-Q15	2.99	3.38	+0.39

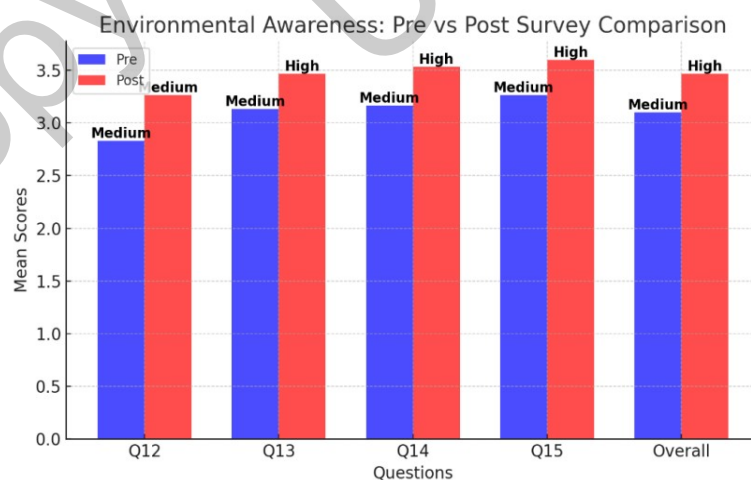


FIGURE 13. Environmental Awareness Result Bar Chart.

The significant increase in environmental awareness shows that the game has successfully influenced players' perceptions and attitudes towards Marine pollution and has delivered a strong conservation message. The increase from 2.99 to 3.38 points to the game's success in educating players about environmental protection.

TABLE 15. Environmental Values Result.

Question	Mean Score (Pre)	Mean Score (Post)	Change
Q16	3.27	3.60	+0.33
Q17	3.23	3.53	+0.30
Q18	3.20	3.67	+0.47
Q19	3.30	3.67	+0.37
Q16-Q19	3.25	3.62	+0.37

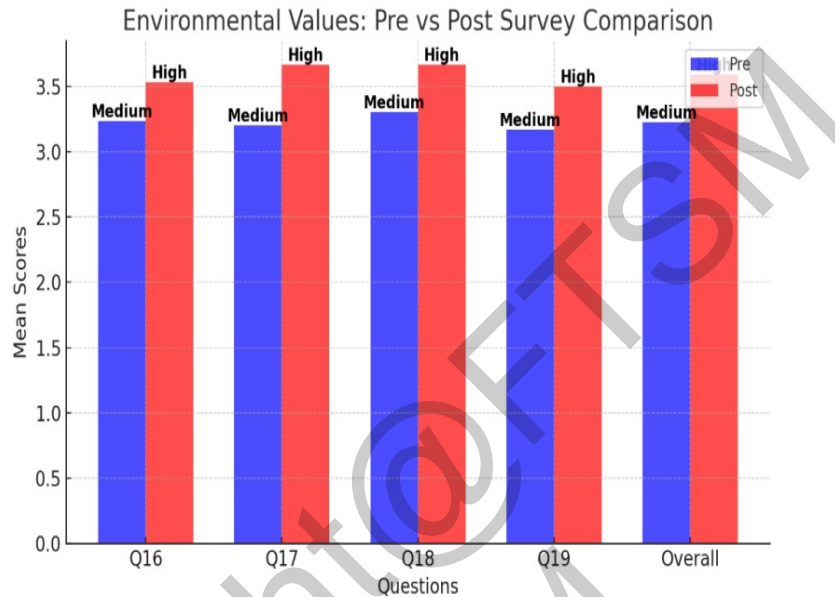


FIGURE 14. Environmental Values Result Bar Chart.

The increase in environmental values shows that players, after interacting with the game, have a greater awareness of the importance of Marine conservation and are willing to take action, which is important to promote players' environmental responsibility. The score in this area improved from 3.25 to 3.62, further demonstrating the effectiveness of games in promoting players' environmental values.

TABLE 16. Environmental Participation Result.

Question	Mean Score (Pre)	Mean Score (Post)	Change
Q20	3.17	3.50	+0.33
Q21	3.30	3.73	+0.43
Q22	3.37	3.57	+0.20
Q23	3.30	3.63	+0.33
Q20-Q23	3.28	3.61	+0.33

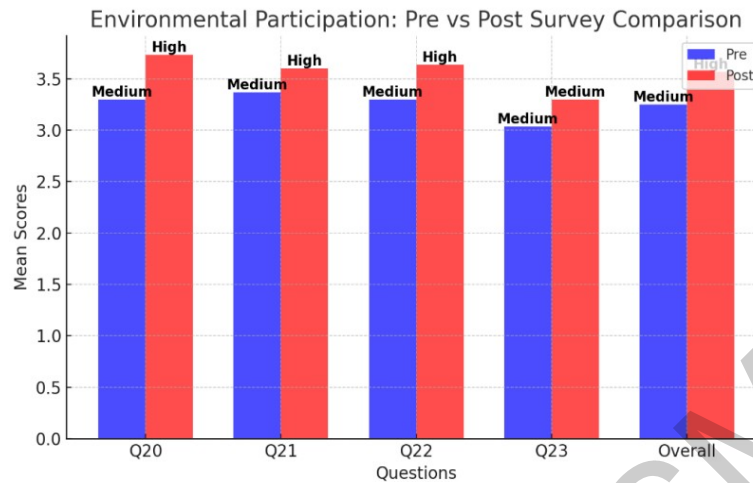


FIGURE 15. Environmental Participation Result Bar Chart.

Finally, the increase in environmental participation indicates that players are more likely to engage in actual conservation activities as a result of the gaming experience, marking a major success in translating virtual learning into real-world action. The score increased from 3.28 to 3.61, reflecting the actual impact of the game in encouraging players to engage in actual environmental activities.



FIGURE 16. Before and After Comparison Across All Questions.

To evaluate the game's educational benefits and capacity to raise environmental awareness, the study carefully examined participant rating changes before and after the game experience. The overall average rating went from 3.05 before to 3.61 after the game, and the rating went from "Medium" to "High." This notable rise shows the potential of games as an educational tool, particularly in increasing public awareness and engagement on environmental issues, as well as the effectiveness of game design in educating participants, particularly in directing them toward environmentally friendly behavior. These findings give game developers an empirical foundation for creating future games that target particular learning objectives, which can enhance user engagement and learning outcomes. This thorough analysis validates study results and offers convincing proof of the usefulness and efficacy of game interventions in real-world settings.

Open Ended Question

Participants can respond to open-ended questions at the end of the questionnaire and those listed above. Open questions are essential to many aspects of this study. In the open questions at the end of the

questionnaire, participants shared their overall experience of the "Marine Conservation War" game, and the feedback showed that the game has a certain educational value in raising awareness of ocean protection. Players praised the game for its entertaining, engaging design and educational nature, especially in raising awareness of marine pollution issues. However, feedback also pointed to deficiencies in the game's actual environmental action guidance, game depth, sustained playability, and technical optimization. Based on this feedback, we plan to add more specific environmental action instructions in future versions of the game, improve the challenge and depth of the game, and optimize the graphics and user interface to enhance the game's overall appeal and educational effect. This qualitative data is critical to understanding the human factors of statistical results, helping to enrich research and guide the iterative development of games.

TABLE 17. Open-Ended Question Answers.

No.	Answer Content
1	This game is exciting, and I learned a lot about Marine pollution while playing it, which gave me a deeper understanding of the problem. Some missions and challenges made me feel like I was helping solve the problem of ocean pollution. After the game ended, I started thinking about how to take action in real life. While the game provided much theoretical knowledge, I wish I had more guidance on implementing these environmental actions concretely.
2	I like this game. It makes me pass the time, but it also makes me realize the importance of protecting the ocean. The game's design is attractive, and it is easy to get started. However, while it is easy to play, there is room for improvement in the game's depth and sustainable playability, which may be why I am slightly less satisfied. Adding more layers and challenges could make the experience more prosperous and durable.
3	Playing this game made me feel that the designers were meticulous, especially in showing Marine environmental issues. I learned much about marine ecology through the game, which I had not known before, and I had a whole new perspective. The game sometimes has a bit of a card, especially in some advanced features, and needs further optimization. However, overall, it is an excellent game to recommend because it lets you play and learn.
4	The game was great because it taught me a lot about ocean pollution and made me feel like I could be a part of it and make a difference. It is rich, educational, and engaging. However, I hope the future version will enhance the graphics and make the experience more fluid, which will better appeal to more players.

Data Validity Analysis

To explore whether changes in different areas were statistically significant, the researchers set the following hypothesis (Yanai & Lercher 2020):

H0 (Null Hypothesis): The usability evaluation of "Marine Conservation War" does not show a statistically significant improvement following gameplay, nor does gameplay significantly enhance players' awareness of marine pollution; that is, $\mu_{pre} = \mu_{post}$.

H1 (Alternative Hypothesis): The usability evaluation of "Marine Conservation War" shows a statistically significant improvement following gameplay, and gameplay significantly enhances players' awareness of marine pollution, i.e., $\mu_{pre} \neq \mu_{post}$.

Pair sample T-tests on participant questionnaire data completed before and after the intervention were run to test these theories. The primary goal of this analytical technique was to determine whether the responses of the same group of participants differed significantly at two different times (i.e., before and after the intervention).

The scientists used a paired sample T-test to confirm the effect of game enhancement on participants' experience. The questionnaire data filled out by the players both before and after the game experience was statistically examined. The main purpose of this analysis technique was to determine whether the answers of the same group of participants differed significantly at two different times (i.e., before and after the intervention).

TABLE 18. T-Test Result.

T-Test	Pre	Post
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Mean (μ)	3.054	3.614
Standard deviation (s)	0.839	0.862
p-value	1.10×10^{-8}	-

The paired sample T-test results found that the P-value was $1.10E-8$, far less than the commonly used significance threshold of 0.05 (Kelter 2020). This extremely low P-value indicates that we have statistically sufficient evidence to reject the null hypothesis H_0 , that there is no significant difference in the average participant satisfaction before and after the game experience. Instead, this result supports alternative hypothesis H_1 , which states a substantial difference in satisfaction before and after a game experience. Specifically, the average level of satisfaction before the game experience was 3.054 but increased to 3.614 after the game experience, showing that participants' overall evaluation of the game experience significantly improved.

This statistically significant result underscores that game improvements significantly affect the user experience. It proves that by optimizing game design, participants can be engaged, and their satisfaction and sense of engagement can be improved considerably. In addition, the magnitude of the change also shows that the game intervention successfully improved the user experience and increased their positive feedback on the game content.

Together, the results of these paired sample T-tests confirm the effectiveness of game design improvements and validate the potential of games as a tool for raising public awareness and engagement. Applying this methodology provides a solid statistical foundation for further gaming and educational technology research.

DISCUSSION

The results highlight ways to successfully enhance the game prototype to inform and involve the public in marine conservation initiatives. They validate the educational value of games and show how well they can pique public interest. Evaluation of the game allows us to determine what has worked well and needs improvement. This offers crucial direction for the next game creation and environmental education initiatives.

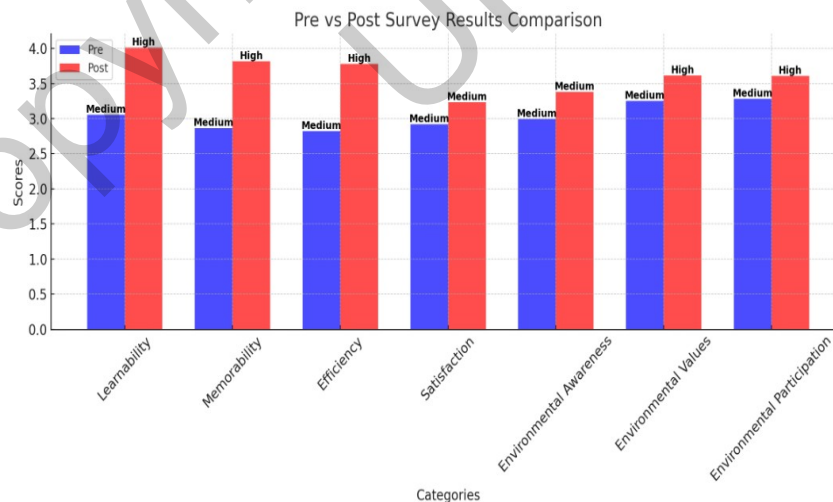


FIGURE 17. Histogram of Comparative Mean Values for Each Area of the Questionnaire.

Through the data shown in Table 19, we can see the effectiveness of the game prototype in educating and raising public awareness of environmental protection. It can reveal the potential direction of further optimizing the game to improve educational effectiveness and player satisfaction. These analysis results validate game design's success and provide valuable insights for future environmental education strategies and game development.

TABLE 19. Summary of Usability and Public Awareness Results.

Area	Aspect	Mean Score (Pre)	Mean Score (Post)	Change
Usability	Learnability	3.06	4.01	+0.95
	Memorability	2.87	3.81	+0.95
	Efficiency	2.82	3.78	+0.96
	Satisfaction	2.92	3.23	+0.31
Public Awareness	Environmental Awareness	2.99	3.38	+0.39
	Environmental Values	3.25	3.62	+0.37
	Environmental Participation	3.28	3.61	+0.33
Total		3.05	3.61	+0.55

Table 20 summarizes the analysis of the game prototype, highlighting its effectiveness in promoting awareness of marine conservation through sustained participation and interaction, thus proving its educational potential. However, the evaluation also identified areas for improvement, such as enhancing the game's interactivity and user interface to make it more intuitive and user-friendly and addressing technical and financial constraints. Future development should focus on strengthening connections to real-world environmental activities and providing ongoing incentives to encourage practical action and long-term engagement. These insights underscore the importance of continued research into the use of games for ecological education and their integration into broader social and educational initiatives. The results emphasize the need for more investment in technology and resources, as well as collaboration with educational and environmental organizations, to enhance the game's interactivity and visual quality. Ultimately, the success of such game prototypes can influence the development of relevant environmental policies and practices, demonstrating their value as tools for raising public awareness and involvement in environmental protection.

TABLE 20. Advantages and Disadvantages of the Prototype.

Advantages	Disadvantages
The prototype showed significant positive results in raising participants' awareness of Marine pollution and its effects. The data shows that after playing the game, there is a substantial increase in concern and knowledge about Marine conservation.	While progress has been made in areas such as environmental awareness, there has yet to be any significant improvement in other areas, such as willingness to act on environmental protection or long-term behavior change. This suggests that games need further refinement to promote real action and deep attitude change.
The game design succeeded in engaging participants and maintaining a high level of engagement, especially in the long periods of engagement and interaction that are often difficult to achieve in educational games.	While games are effective in terms of education, feedback from participants suggests that there is still room for improvement in the game's interactivity and user interface, especially in terms of increasing intuitiveness and user-friendliness.
Games have shown particular effectiveness in specific educational goals, such as raising awareness of marine ecological protection, and have confirmed their effectiveness as educational tools.	Technical and financial resources limited game development, which may have affected the implementation of some advanced features, such as more complex interactivity and high-quality graphical presentation.

CONCLUSION

This study explores innovative educational models and game design in the field of environmental education, aiming to raise public awareness of marine protection through gamification methods. The research makes three key contributions: developing a new educational model that integrates serious game elements, software design principles, and environmental awareness to support marine conservation; enhancing game design by optimizing incentive mechanisms and employing modular and personalized strategies to improve educational value and player motivation; and creating the "Marine Conservation War" game, which effectively combines educational content with engaging game mechanics to raise awareness about marine pollution.

Through in-depth analysis and implementation of various game design optimization strategies, the study successfully combines serious game elements, software design principles, and environmental protection education to develop a new education model. By identifying relevant theories and techniques, creating and prototyping a serious game model, and using usability evaluation to confirm the game's efficacy, the research shows that serious games can be powerful tools for increasing public awareness of marine pollution and sustainable development. The findings offer valuable strategies and insights for future applications of serious games in environmental protection, demonstrating the potential and value of gamified learning in promoting the global Sustainable Development Goals.

Future work will focus on expanding game features and educational content to cover more marine conservation topics, verifying the game's effectiveness across different cultural and geographical contexts, and incorporating multiplayer features to enhance social and educational potential. Additionally, machine learning and artificial intelligence methods will be explored to personalize the gaming experience, while thorough evaluations in diverse settings will ensure the game's universal applicability and effectiveness as a global environmental education tool.

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