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An augmented reality board game to work ocean literacy dimensions

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Abstract

Over the past decade, research has stressed the necessity of increasing ocean teaching in formal and informal education by addressing ocean literacy dimensions. Although board games have emerged as an affordable and accessible option for immersive learning experiences, limited empirical evidence demonstrates their effectiveness in enhancing students' understanding of ocean-related concepts. Board games can encourage face-to-face interactions among peers or teams by combining tangible materials with turn-taking modes and promote students' engagement with multiple aspects of ocean literacy. The present work aimed to develop an augmented reality (AR) game-based educational tool (The Blue Bounty) to inform about the ocean and explore how this could help improve engagement with different ocean dimensions. The development process followed a co-design approach with university students, based on the Design, Play and Experience (DPE) framework. The game was used in an intervention to assess its ability to address six relevant ocean literacy dimensions in a pre/post assessment design. The findings from the game activity show that the research tool has the potential to significantly increase various dimensions, including knowledge acquisition, awareness enhancement, communication skills, attitude formation, activism engagement, and behaviour change, more than a control traditional lecture. Each dimension is impacted differently, highlighting the multifaceted benefits of integrating these activities into formal and informal environments. Additionally, the results suggest that increasing knowledge may have a positive impact on awareness, communication, attitude, activism and the behaviour layer. Discussion includes implications for the development of more engaging environmental educational tools, including the design, implementation, and measurable outcomes.

Keywords Ecosystem services · Energy · Fisheries · Game-based learning · Ocean economic activities and pressures · Tourism

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1 Introduction

Over the past several decades, trends in anthropogenic climate and land cover change have resulted in an increased frequency of extreme weather events (Du et al., 2023; Loureiro et al., 2023). Such events have significant implications for the global water cycle, and consequently, the ocean has experienced unprecedented change. The ocean covers 71% of the planet's surface, holds 97% of its water, and supports 80% of its life forms. It is a critical component of Earth's biodiversity and an abundant source of sustenance, yielding nourishment, medicinal resources, and valuable energy reserves. Besides, the ocean plays a pivotal role in Earth's climate regulation, deeply connecting all aspects of human life (Dupont et al., 2023; Jaspars et al., 2016; Jenkins et al., 2023; Tjiputra et al., 2023). Despite the ever-increasing global awareness of the climate, pollution and biodiversity crises, research has shown low levels of understanding of marine environmental issues and awareness of the ocean's impact on our lives

(Frick et al., 2004; author(s); Pantò, 2019). Students and adults from various countries exhibit limited comprehension of ocean-related subjects (Costa & Caldeira, 2018; Freitas et al., 2022; Guest et al., 2015; Winks et al., 2020). This insufficient concern about the severe deterioration of the natural environment has been attributed to people's lack of understanding and engagement with the matter (Campbell et al., 2023; Hügel & Davies, 2020; Wannewitz & Garschagen, 2023). Given our planet's pressing environmental challenges, engagement with these scientific topics can enable citizens to make more conscious personal and societal decisions about the ocean and raise hope for progress towards Paris Agreement goals. It is one of the biggest challenges of our generation, and as we intensify our efforts to achieve net zero, it is critical to continue raising ambitions and engaging citizens in adopting more pro-environmental behaviours and acting sustainably.

Education institutions play a key role in promoting environmental and ocean literacy and critical thinking skills among individuals (Everth & Bright, 2023; Taimur & Sattar, 2020). In particular, in increasing understanding of the ocean's importance to our daily lives, our impact on the ocean and enhancing communication about the ocean in a meaningful way, leading to informed and responsible decisions (Cava et al., 2005; O'Brien et al., 2023; Santoro et al., 2017). Consequently, integrating marine science into the education curriculum has become a key issue to expand and promote pro-environmental behaviours. Reinforcing these arguments, global initiatives such as the 2021–2030 UN Decade of Ocean Science for Sustainable Development have stressed the importance of education for sustainable development to improve the relationship between society and the ocean (Heymans et al., 2020). Nevertheless, some authors have questioned the knowledge-deficit model, which attributes a direct relationship between environmental knowledge and pro-environmental behaviours (Goodale, 2020; Heimlich & Ardoin, 2008; Huoponen, 2023; Kollmuss & Agyeman, 2002; McKinley et al., 2023). Aligning with this, the need to shift to models that foster active participation, connection and engagement has been emphasised (McKinley et al., 2023;

Mercer et al., 2017; Visbeck, 2018). Models nurturing multiple aspects or dimensions of ocean literacy were then proposed, expanding from an approach transferring information about the ocean and our impact based on knowledge, communication and behaviour (Cava et al., 2005) to one considering three additional dimensions: attitude, awareness and activism (Brennan et al., 2019). Later on, four new dimensions were suggested: emotional connections, access and experience, adaptive capacity, and trust and transparency (Mckinley et al., 2023). Globally, research has over and over again highlighted the necessity of improving citizens' ocean knowledge by incorporating marine science topics into formal and informal education. This would promote better engagement and understanding of the interconnection between individuals and the ocean, which is mentioned across different ocean literacy dimensions (Brennan et al., 2019; Kelly et al., 2022; O'Brien et al., 2023). Nonetheless, even though engagement has been recognised as playing a critical role in promoting sustainable pro-environmental behaviours, empirical studies exploring how to design more engaging ocean literacy experiences are still scarce.

2 Enhancing ocean literacy: information and engagement strategies

Drawing on an extensive range of sources, learning environments that include interactive features, clear goals and immediate feedback has been instrumental in fostering active learning, thereby engaging additional cognitive events during the learning process (Csikszentmihalyi & LeFevre, 1989; T W Malone & Lepper, 1987; Malone Thomas, 1982; Prensky, 2005). Similarly, game-based learning possesses these features to potentially engage individuals in addressing issues concerning climate change and environmental sustainability. The literature on the topic has reported that the use of games and gamified mobile applications can foster the learning experience, attitudes, motivation and behaviours towards the environment (Boncu et al., 2022; Douglas & Brauer, 2021; Fox et al., 2020; Gu et al., 2023; author(s); Neset et al., 2020). According to the constructivist theory, learning is an active and constructive process. Students are not passive recipients of information but rather builders of their own knowledge, constantly interacting with the learning environment to form new experiences based on existing ones (Biggs, 1996; Chaillé & Silvern, 1996; Doolittle & Hicks, 2003; Vygotsky, 1978). Experiential learning emphasises active learning from direct experience can encourage critical thinking and provide students with more opportunities for decision-making (Fowler, 2008; Nicolopoulou, 1993). The integration of games as pedagogical tools can offer students an opportunity to actively participate in the learning process, fostering reflective thinking and experiential learning. In the literature, the integration of interactive experiences encouraging students to explore the science context deeper has been associated with a higher level of learning and behavioural change (Boncu et al., 2022; Douglas & Brauer, 2021).

Behind much of the environmental science lies a series of scenarios that serve to test social assumptions. In many cases, these scenarios have been designed to explore a range of potential developments under changeable conditions (Guan

et al., 2023; Hazeleger et al., 2015; Liguori et al., 2021; Shepherd et al., 2018). These approaches seem to hold the potential to function as a heuristic tool for decision-making in the environmental field because they can facilitate the translation of complex or more challenging information into easily understandable concepts. In this form, the information load is reduced. These features seem to facilitate engagement with an audience, capture their attention and make them want to listen and learn (Hill & Grinnell, 2014). Likewise, games have the potential to offer students topic-based scenario simulations through well-designed storylines even when real-time live experiences could be impractical due to physical limitations. It can provide a narrative facilitating active participation and reflection, resulting in stronger metacognitive development (Bowman & Standiford, 2015; Kelly et al., 2022; Tsai et al., 2019). These learning experiences hold immersive features that stimulate autonomous thinking and higher levels of cognitive engagement, having the potential to provide pathways to mastery through entertainment and fun (Chen et al., 2024; Jaramillo-Mediavilla et al., 2024). In recent years, there has been an increasing amount of literature on the impacts of incorporating board games in learning settings (Díaz et al., 2024; Martindale et al., 2024; Noda et al., 2019; Robinson et al., 2021). The literature highlights affordability and accessibility features and seems to possess the capacity to encourage face-to-face interactions among peers or teams through the combination of tangible materials and turn-taking modes (Bayeck, 2020; Cheng et al., 2019; Eisenack, 2013).

Consequently, this research aimed developing an AR game-based educational tool within the ocean literacy context and to explore how this could help improve engagement with different ocean dimensions, clarify how they may relate to each other and if they could trigger behavioural change. The working hypothesis was that the AR board game co-designed within the Design, Play and Experience (DPE) framework (Winn, 2009) could be more effective in increasing students' knowledge and other relevant dimensions than the classical teaching approach. Besides knowledge, the dimensions considered were awareness, attitude, communication, behaviour and activism. To tackle the established objective the marine board game incorporating augmented reality (AR) was developed and employed in data collection, analysis and visualisation. The game was based on multirole scenarios and named *The Blue Bounty*. The game-based learning experience involved four key features: i) a multirole simulation to comprehensively present the topic and enable students to understand the interaction between the different roles. Players should reach a consensus on addressing the issue; ii) a systemic situation, which transforms the diverse cause-and-effect relationships that constitute the intricate topic, into a game process by utilising the game's rules and feedback mechanics; iii) reflective goals where players must adopt critical thinking, consider the development of others and undertake actions to safeguard the public interest; and iv) player interactions, allowing participants to share their views on public issues with others. The results obtained were useful to gain insight into how to design more engaging educational tools and strategies for enhancing pro-environmental behaviours.

3 Materials and methods

3.1 AR board game design: A Participatory approach

Participatory design is an approach that emphasises the importance of involving the users as partners during different stages of the design process (Fowles, 2000; Muller et al., 1993; Titlestad et al., 2009). This approach was followed to facilitate a deeper understanding of users, ensure more user-centred and engaging solutions and provide opportunities for participants to provide insights and feedback (Ampatzidou & Gugerell, 2019; Khaled & Vasalou, 2014; author(s)). This stage involved user testing of a low-fidelity prototype through observation and taking notes by the researcher. It was intended to promote participants' involvement in the research tool development from a student's viewpoint, express their needs and generate ideas. The prototype is related to main ocean economic activities and potential pressures; fisheries, tourism and energy. The game was thought to involve the roles of a commercial fisherman, a tourism entrepreneur and an energy company manager, representing in this way different scales of enterprises in the ocean economy. Commercial fishermen were included to partake in fishing operations within the fish stock and engage in aquaculture endeavours within the mangrove forests. Tourism entrepreneurs were considered for the management of coastal resorts and delivery of marine leisure pursuits, such as entertainment cruises along sailing routes, and an energy company manager was considered for their involvement in mining activities within the deep sea, a highly discussed actual issue. The Design, Play, and Experience (DPE) framework (Winn, 2009) was adopted in order to explore the balance between playability and knowledge transfer among the participants in an earlier stage of the design development.

3.2 Effect of the AR board game on literacy dimensions

The AR board game developed was then used to assess the working hypotheses in a convenience sample. The study sample consisted of 36 UK university students aged 18 to 25. Ten of these participants were male, and 26 were female. The participants were randomly divided into two groups: Group 1 interacted with an AR board game (Figure 1), while Group 2 served as the control group and experienced a traditional session simulation with oral explanations. All the participants were asked to complete a pre-test assessing different ocean literacy dimensions. The pre-test and post-test questionnaires were based on the Brennan et al. (2019) ocean literacy framework, which encompasses six dimensions: knowledge, awareness, communication, attitude, activism and behaviour. In order to understand the game-based learning effects on different levels each dimension was evaluated independently before and after the intervention. To assess participants' knowledge, multiple-choice questions were selected and for each of the other five dimensions, two questions were considered, all of which had responses on a 5-step Likert scale (Tables 1 and 2). The surveys were anonymous, and no personal

Fig. 1 Group 1 experiment with the AR board game. Gameplay scene

information was collected. To comply with research ethics requirements, permission was obtained from the participants regarding their participation in the study.

3.3 Data analysis

A global score was estimated for each assessed dimension and participant, based on the responses of the two groups (i.e. type of intervention, namely the game or the traditional session simulation) to the questionnaires before and after the intervention (pre *vs* post moments). The data were statistically analysed with repeated measures analysis of variance (ANOVA), using the group as fixed factor and the moment of assessment (before or after intervention) as the repeated measures factor. When significant differences were found, pairwise comparisons were made with *t*-student tests using the Bonferroni correction to control for the family-wise error rate. Correlations among the six investigated dimensions were estimated with the Pearson correlation coefficient. All tests were performed in SPSS version 26 with a significance level set to 0.05.

Table 1 Questionnaire items used to assess ocean literacy knowledge dimension. The items were of Likert scale response (multiple choice)

Questionnaire items
How is sea level measured?
A. Average depth of the ocean B. Average height of the ocean relative to the land C. Level of the ocean at the lowest tide D. Level of the ocean at the highest tide
Most rain that falls on land originally evaporated from:
A. The tropical region of the ocean B. The temperate region of the o0ean C. The nearby lakes and rivers D. The ocean nearest the land where it fell
What is the difference between weather and climate? Choose the best answer
A. Weather is what is happening right now, and climate is what happened last year B. Weather is what is happening now, and climate is what happens over many years C. Climate is what is happening right now, and weather is what happens over many years D. Weather is everywhere while climate is local
Where did most of the oxygen in the atmosphere originally come from?
A. The same processes that formed the Earth B. Photosynthesis by plants on land C. Respiration of animals D. Photosynthesis by organisms in the ocean
What is the largest animal ever to live on Earth?
A. Giant squid B. Orca (killer whale) C. Blue whale D. Tyrannosaurus rex
Most of the biomass in the ocean resides in:
A. Fishes B. Plankton C. Mammals D. Molluscs

4 Results

4.1 The blue bounty board game: connecting ocean literacy to game dynamics, mechanics, and components

The game-based learning framework facilitated the student's contribution to the game iterations through the analysis of four different game dimensions: learning, storytelling, gameplay and user experience. A low-fidelity prototype was developed and the experiment was carried out with six university students aged 19–25 from different educational fields (Fig. 2). Students were asked to interact with the board game, provide comments and pose questions if anything was unclear. Feedback and observational data were recorded in the different dimensions of the DPE framework and in field notes, and used to improve the game. Data were collected anonymously.

Table 2 Questionnaire items used to assess ocean literacy dimensions of awareness, communication, attitude, activism and behaviour (after Brennan et al., 2019). The items were of Likert scale response (do not agree up to completely agree; five levels)

Questionnaire items
Awareness
The ocean is crucial for human well-being, it is deeply connected to all aspects of our lives
The unsustainable human activities on the ocean damage its ecosystem and the ability to provide resources on which human depends
Communication
I will communicate with others about threats created by humans on the ocean
I will communicate with others about how to protect the ocean
Attitude
I support projects to restore the health of the ocean
I'm very worried about the problems our oceans are facing
Activism
I'm willing to get involved in ocean conservation actions
I'm willing to engage in campaigning through social media and attending public rallies
Behaviour
When choosing a vacation beach, I place more emphasis on low-carbon transport rather than just considering the price
I'll insist on proper waste disposal and living as plastic-free as possible

Fig. 2 Tokens manufactured on wooden boards. Laser cutting workshop. Prototype development

The findings of the co-design workshop showed the board game hold engaging characteristics and had the potential to foster social interaction and teamwork among students. This earlier test in the design process facilitated participants' contributions to enhance the game learning experience, storytelling, and gameplay through a co-design approach. Regarding the learning, changes introduced involved expanding the ocean topics through multiple-choice quiz questions to improve the variety and quality of the learning and to improve the time balance of the gameplay (Figure 3).

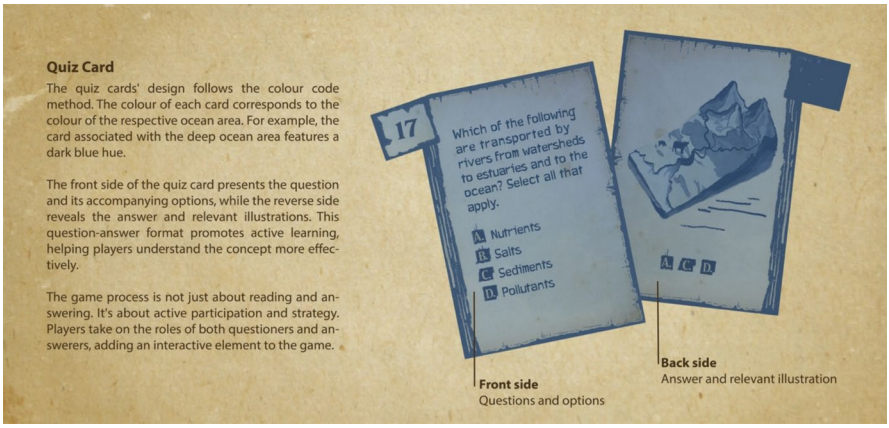

Fig. 3 Quiz card design with questions and options on one side and answers on the backside based on the ocean literacy survey developed by Fauville et al. (2019)

Participants' contributions to the storytelling level included updating the government reward to event cards. The events included in this mechanic became connected to respective areas on the game board, making clearer connections to impacts and thus promote environmental awareness (Fig. 4). Regarding the gameplay, the distance between ecosystems in different areas of the ocean was made clearer and the reward system was updated to improve the game interaction. Group cooperation challenges were reinforced over the individual competition. The experiment also contributed to improving the progress balance, such as building and rescuing cannot be carried out simultaneously in one round and the number of events cards. At the user experience level, the legibility and readability of the scientific content were

Fig. 4 Event cards

improved. The visual style was redesigned to provide stronger visual environment consistency, and the points of AR image tracking points were adjusted to improve the interaction with this layer of information.

The final version of the AR board game comprised five main game mechanics. The first involved a multi-role simulation. To facilitate the participants' comprehension and explore the perspectives regarding the diverse actions undertaken by various ocean stakeholders, the players randomly take on the role of a commercial fisherman, tourism entrepreneur and energy company manager within each team (Fig. 5). Additionally, the game was thought to present decision-making scenarios requiring the player to apply their newly acquired knowledge to make choices and take action. The second mechanic was a quiz-based approach. Players arbitrarily choose a plot within their active territory and answer questions corresponding to that plot. Correct answers lead to plot occupations and start-up funds for subsequent rounds. The quiz is based on the ocean literacy survey developed by Fauville et al. (2019) to measure marine knowledge across the world (Fig. 3). The third mechanic developed is the encounter of events. Players have a good chance of drawing *'Event Cards'* within the plots. Players who are impacted by this event and the group's ocean health points will have their personal property deducted. The ocean health points are calculated using both eco-health points and bio-health points. The fourth mechanic was thought to balance the ocean's benefits and health (Fig. 5). Players build corresponding facilities within the territories they occupy. Their ocean-related actions result in profits while exerting negative effects on the ocean. At this point, players can invest in remediation efforts aimed at restoring the impacted ocean. Players can only recover negative impacts caused by themselves. For example, the *'New Blasting Tech'* can only be initiated by the energy company manager, while *'Trash Clean-up'* is accessible to all three players. The fifth mechanic was related to the coexistence of cooperation and competition. It allows competition between different groups of players, the winning group determined by the highest ocean health points and comprehensive

Fig. 5 Role card design concept

economic gains. Concurrently, collaborative dynamics emerge among players belonging to the same group. A *'Tsunami'* is triggered when the eco-health points or the bio-health points reach a critical threshold of −11, leading to a 5-coin penalty on all three members within the group. A further decline to −16 signifies *'A Dead Ocean'*, resulting in a collective defeat and the end of the game.

Another pivotal aspect taken into consideration in the co-design was to allow game maps and cards to be scanned by electronic devices, where a sequence of animations can then provide a reinforcement of the information and, consequently, stronger student support through the learning experience (see Figure 6). Including augmented reality (AR) in a board game can add a second layer of information design and widen learning opportunities. AR technology can strengthen the connection between thematic scenarios and real-life situations, enhance students' interactivity with knowledge, facilitate visualising information that is challenging to understand in 2D form, and provide more learning guidance facilitating students' cognitive scaffolding (Hou et al., 2023; author(s); Lin & Hou, 2024).

The overall results from the participatory workshops demonstrated that this approach can provide valuable insights into design development and facilitate drawing conclusions by going from the specific to the general. Consequently, facilitated the exploration of relationships and the recognition of patterns between the topic, the game scene and participants. The Design, Play, and Experience (DPE) framework (Winn, 2009) has been demonstrated to be a supportive tool for integrating the different game components and the different Ocean Literacy dimensions. The framework allows for iterative exploration of these different layers and balanced integration. Therefore, it has the potential to foster student engagement and enhance pro-environmental behaviours.

Fig. 6 AR card animation with information about the noise pollution impact on the ocean

4.2 Quantitative assessment of the blue bounty's impact on the ocean literacy dimensions

The findings of the questionnaire about the Ocean Literacy dimensions revealed an initially low level of knowledge among the participants (Fig. 7). The results suggest that university students are aware of ocean-related issues, which is a positive step towards addressing them. Despite the myriad components of ocean communication, this study considered communication as the extent to which a person communicates with others, such as family and peer groups, on ocean-related topics. Findings suggest there is low engagement at the communication level. Students demonstrate good attitudes and an understanding of suitable behaviours towards ocean protection. The attitude dimension is related to the degree of alignment with or concern for, from a specific standpoint. The students exhibited insights on the societal repercussions of interventions in ocean management and comprehension of attitudes towards governance procedures. Regarding activism, the participants seem to hold low motivation to engage in ocean-friendly actions. These results can be related to the dangers some students consider when engaging in environmental actions. In the behaviour dimension, students seem to hold good individual decisions and habits regarding ocean-related issues. However, this study did not measure the actual behaviour of participants, but the intended behaviour through a questionnaire.

The statistical analysis showed that all the ocean literacy dimensions increased in both groups (Fig. 7, Table 3). However, the results obtained from the students showed the AR board game had a stronger effect on the knowledge and awareness levels, compared to the traditional teaching session (Table 3). These findings reinforce the importance of increasing opportunities for student engagement with ocean-related topics. Expanding access to game based educational experiences seems to enhance students' knowledge and also engagement with the topic, ultimately contributing to ocean preservation for future generations. Although there is a growing awareness of environmental issues, students increased more their consciousness after engaging with the game than in the traditional lecture (Table 3). For the

Fig. 7 Effects of The Blue Bounty (Group1) vs the traditional learning session (Group 2) on ocean literacy dimensions; pre-post intervention. Different letters indicate statistically significant differences among groups (Knowledge and Awareness, $p < 0.05$), while the star indicates statistically significant differences in the post-test, relative to the pre-test (with no differences between groups, $p < 0.05$)

Table 3 Results of the Repeated Measures ANOVAs done to investigate effects of The Blue Bounty on literacy dimensions. No significant differences were found between groups for any of the dimensions

Knowledge					
	Sum of Squares	df	Mean Square	F	p
Moment	1.581	1	1.5812	65.67	<.001
Moment x Group	0.123	1	0.1225	5.09	0.031
Residual	0.819	34	0.0241		
Awareness					
	Sum of Squares	df	Mean Square	F	p
Moment	0.18	1	0.18	22.25	<.001
Moment x Group	0.045	1	0.045	5.56	0.024
Residual	0.275	34	0.00809		
Communication					
	Sum of Squares	df	Mean Square	F	p
Moment	0.5689	1	0.5689	54.66	<.001
Moment x Group	0.0272	1	0.0272	2.62	0.115
Residual	0.3539	34	0.0104		
Attitude					
	Sum of Squares	df	Mean Square	F	p
Moment	0.3613	1	0.36125	54.12	<.001
Moment x Group	0.0168	1	0.01681	2.52	0.122
Residual	0.2269	34	0.00667		
Activism					
	Sum of Squares	df	Mean Square	F	p
Moment	0.605	1	0.605	46.63	<.001
Moment x Group	0.0139	1	0.0139	1.07	0.308
Residual	0.4411	34	0.013		
Behaviour					
	Sum of Squares	df	Mean Square	F	p
Moment	0.46722	1	0.46722	91.35	<.001
Moment x Group	0.00889	1	0.00889	1.74	0.196
Residual	0.17389	34	0.00511		

remaining dimensions, although the results were always slightly higher in Group 1, compared to Group 2, no statistically significant differences could be identified. This probably occurred because the of limitations imposed by the samples sizes and the groups exhibited high to very high performance in many dimensions before the intervention, as indicated by the high scores in the pre-test (Fig. 7). It is worth noting the relatively low initial pre-test level regarding the communication dimension. This is probably the reason for the effectiveness of the intervention and the significant differences found in the post-test, compared with the pre-test (Table 3). The results suggest it had a strong effect on students' willingness to discuss ways of mitigating the problems we cause in the ocean with family, friends and colleagues. They were

more aware of the problems our ocean is facing and more motivated to support projects to restore the health of the ocean. The activism dimension also increased with the intervention suggesting that the students were more motivated to engaged and participating in activities such as attending public pro-environmental events or campaigning through social media. Responses also showed a significant effect on the students' behaviours (Fig. 7, Table 3) suggesting they were more engaged in improving their lifestyle choices and pro-environmental habits, as well as in taking action to reduce the negative effects of coastal tourism. Overall, the results showed the Blue Bounty AR board game had a positive effect on knowledge, awareness, communication, attitude, activism and behaviour dimensions. Furthermore, the game experience was more effective in improving the students' knowledge and awareness than the traditional lecture.

4.3 Correlation among ocean literacy dimensions

An analysis based on the Pearson coefficient showed the intervention (i.e. the AR game board and the traditional lecture) resulted in statistically significant positive correlations between different dimensions that were not observed initially (Figure 8). Although the small sample of participants could have influenced the results, the Pearson's heatmap matrix (Figure 8) revealed significant positive correlations between knowledge and all other dimensions after the intervention, ranging from 0.34 (between knowledge and communication) to 0.53 (between knowledge and attitude). Significant positive correlations were also found between awareness and communication (0.59) and between awareness and behaviour (0.65). The highest positive correlation found was that between communication and attitude, which increased from 0.57 in the pre-test to 0.81 in the pots-test. (Figure 8). These results suggest that increasing knowledge may have a positive impact on awareness, communication, attitude, activism and the behaviour layer. Additional research is needed to better understand these relationships and how to design more effective ocean information.

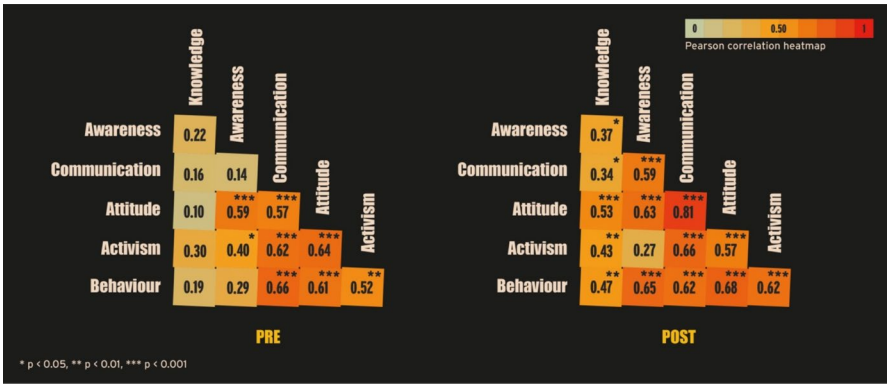

Fig. 8 Pearson's heatmap correlation matrix of data results: pre-post test. Multicollinearity arises when variables in the model exhibit substantial correlation

5 Discussion

Studies on the specific combination of AR with ocean board games are scarce in the literature. A recent study integrated AR into a board game to support elementary school pupils in developing their coding skills and enhancing computational thinking concepts (Huang et al., 2023). This game board provided players with real-time simulation of ship paths and learning scaffolds. The results showed that compared to a control group, the AR board game can increase the effectiveness of computational thinking and learning performance of base programming skills while keeping a low cognitive load. The present work showed similar results, pointing out that including augmented reality (AR) in a board game can add a second effective layer of information design and widen learning opportunities. This aligns with other works indicating that AR technology can strengthen the connection between thematic scenarios and real-life situations, enhance students' interactivity with knowledge, facilitate visualising information that is challenging to understand in 2D form and provide more learning guidance, facilitating students' cognitive scaffolding (Hou et al., 2023; Lin & Hou, 2024; Wu et al., 2013). Findings based on the Design, Play, and Experience framework show a positive balance among the different components. This suggests that the Blue Bounty research tool processed a strong balance of design, playability and knowledge transfer. This study aimed to understand how interacting with an AR board game in learning activities can affect different ocean literacy dimensions. The findings from the game activity show that the research tool has the potential to positively influence various Ocean Literacy dimensions, including knowledge acquisition, awareness enhancement, communication skills, attitude formation, activism engagement, and behaviour change. Each dimension is impacted to different degrees, highlighting the multifaceted benefits of integrating these activities into formal and informal contexts.

5.1 Knowledge dimension

The knowledge dimension is commonly at the heart of ocean literacy and one of the most explored topics in the environmental education literature. Although it is commonly assumed as a precondition for achieving sustainable ocean-related behaviour, previous works suggested that only a small fraction of pro-environmental behaviour can be directly linked to environmental knowledge (Huoponen, 2023; Kollmuss & Agyeman, 2002; Liu et al., 2020). This study revealed the AR board game was able to significantly increase knowledge and awareness, compared to the control group, acting also on the other dimensions assessed. As designed, the AR board game seems to possess the ability to increase the students' knowledge about ocean-related topics, and this is connected to different ocean literacy dimensions. The quiz card game mechanic seems to facilitate participants' engagement in thinking about answers and connecting them to actions. This may have influenced the positive effect on the participants' understanding of the ocean. In addition, relevant correlations between knowledge and all other dimensions were found after the intervention.

These findings suggest that these layers may need to be considered simultaneously and cannot be designed individually in ocean education. However, there is room for further progress in confirming and validating these relationships.

5.2 Awareness dimension

Awareness can be defined as the basic knowledge that a situation, problem, or concept exists. Ocean awareness involves not only the perception and understanding of threats but also the changes and options available(Brennan et al., 2019; Cava et al., 2005). Furthermore, ocean awareness includes both cognitive and affective components. The research findings indicate that students started with a good awareness of the environmental challenges facing the ocean. Nevertheless, the board game has shown to be effective in increasing this dimension and, consequently, the understanding of the solutions and behaviours that may exist to address these problems. These results could have been influenced by the students' opportunity to explore the ocean topics and its connection to our lives through role-playing mechanics. This process allowed them to experience the consequences of their actions, fostering awareness and a sense of ownership. Findings indicate that the board game features positively improved awareness. However, as highlighted by Stoll-Kleemann (2019) more studies are needed to bring evidence that more awareness of the ocean topics directly leads to sustainable behaviour.

5.3 Communication dimension

Effective communication within the context of ocean literacy involves diverse perspectives. Ocean communication has been described as the extent to which a person communicates in a meaningful way with others, such as family and peer groups, about ocean-related topics (Brennan et al., 2019; Cava et al., 2005). Nevertheless, future research should also be considered to understand whether and how ocean and climate greenwashing, misinformation and fake news influence individuals' policy-relevant beliefs and behaviours. The results of this study showed a significant effect on the communication layer of the board game and the traditional lecture. A strong correlation between communication and attitude or activism was also found. The face-to-face gaming environment seems to facilitate active participation and motivate students to speak. Throughout the gameplay, students could have felt a sense of safety and a relaxed setting, allowing them to express their ideas freely. The game decision-making opportunities, role-playing experience within the virtual world, and problem-solving approach in team collaboration also motivated students to speak and discuss ideas. Although poorly explored in the available literature, eco-anxiety is a concept commonly associated with negative environmental information, which can develop negative emotional responses, such as distress and a sense of despair (Coffey et al., 2021; Shao & Yu, 2023). In this study, the board game seems to be a source of motivation for active discussion and engagement in mitigation actions in an enjoyable practice. Students were willing to invest more time and effort in playing the game, to experience other ocean science game-based learning activities and

to share ideas. These findings reinforce the literature on board game learning tools, indicating an increase in interpersonal interactions among participants (Noda et al., 2019).

5.4 Attitude dimension

The attitude dimension is connected to a level of agreement with or concern for a particular position. Attitudes are general evaluations people hold in regard to themselves, other people, objects, and issues. According to Petty and Cacioppo (1986), these evaluations can be based on a variety of behavioural, affective, and cognitive experiences, and can influence or guide behavioural, affective, and cognitive processes. Research on ocean literacy attitudes commonly involves perceptions, values, self-beliefs, interests, and motivations. Jefferson et al. (2014) underline that societal attitudes and perceptions towards the ocean are critical in designing interventions to foster ocean conservation. In this work, the game may have initiated a new behaviour process leading to an increase in the student's motivation to support projects about restoring ocean health. The literature shows that lasting changes in attitudes are more likely to result from deep engagement in an environment, such as playing with a message via issue-relevant thinking (Goldberg et al., 2020; Petty & Cacioppo, 1986; Roozenbeek & van der Linden, 2019). Goldberg et al. (2020) suggest that attitudes formed via deep engagement in a game-based experience are often more consistently organised around core principles in one's belief system. Furthermore, Pearson coefficient analysis shows a strong correlation between participants' attitudes and the communication layer ($p<0.001$ significance level).

5.5 Activism dimension

According to Brennan et al. (2019), activism is the degree to which a person engages in different activities such as campaigning through social media, attending public rallies or writing to elected officials to bring changes in policy, attitudes, behaviour, etc. In this context, activism is defined as taking actions to promote environmental change. This concept is recognised as a fundamental element in the field of educational science. It goes beyond the acquisition of abstract knowledge and involves the ability to effectively address and initiate change in response to prevailing issues. Activism is realised by concrete actions (Ganglbauer et al., 2013; Roth, 2010). The role of environmental activism in the field of educational science has become essential for enhancing the actions for implementation, compliance, and regulation of environmental policies. Nevertheless, Hasler et al. (2020) stress that "protecting the environment through protest has become an increasingly dangerous endeavour with harassment, persecution and death of activists occurring at the hands of both states and corporations" (Hasler et al., 2020, p. 517). This study found a positive effect of the game session on this ocean literacy dimension, encouraging students to engage in environmental activism. This may be related to the game storytelling features, such as the role-playing activity involved in the game development. This study analysis shows a strong correlation as well between this dimension and communication.

5.6 Behaviour dimension

The ocean literacy behaviour dimension involves the individual's decisions, choices, actions, and habits regarding ocean-related issues (Brennan et al., 2019; McKinley et al., 2023). Central to all the problems that have a damaging effect on the environment is the waste produced by our massive collective behaviour and automated lifestyle choices. Likewise, Stoll-Kleemann (2019) noticed that we have the potential to contribute to more sustainable futures on land and in the seas by exercising our consumer choice. However, a behaviour change will only occur when an individual possesses both the capability and opportunity to engage in their preferred behaviour. Additionally, the individual must be motivated to choose the preferred behaviour over alternative options (Michie et al., 2011). Findings indicate that the Blue Bounty board game had a positive impact on the students' behaviour. These results align with the literature showing that game-based interventions for behaviour change have been successfully applied in several fields, such as education, health and the environment (Baranowski et al., 2008; Boncu et al., 2022; Douglas & Brauer, 2021; Takaoka & Jaccheri, 2024). These results may be due to the fact that games potentially increase engagement with environmental behaviour change. The game challenges, fantasy and curiosity, decision-making opportunities, and the game aesthetics can nurture feelings of pleasure and have the potential to initiate a behavioural change process.

6 Study limitations and future research

It is important to highlight that this study did not measure the real participant behaviour but the intended behaviour. Pearson coefficient analysis shows statistically relevant correlations between behaviour and all other dimensions, suggesting they may be directly related. It could be argued that the positive results were due to the small sample size. Consequently, further research is needed, focusing on pro-environmental behaviour and its relationship with the other dimensions of Ocean Literacy. Nevertheless, further studies should be conducted with a larger sample to better understand how face-to-face game-based learning activities can affect different dimensions and how they are interrelated. This study also highlights the need for more research that explores how board games can effectively contribute to ocean literacy, including their design, implementation, and measurable outcomes on students' knowledge and attitudes toward ocean conservation.

7 Conclusion

This study aimed to evaluate the impact of an AR board game in learning activities on ocean literacy dimensions. The findings show that the research tool positively affects various Ocean Literacy dimensions, including knowledge acquisition, awareness enhancement, communication skills, attitude formation, activism engagement, and behaviour change. Each dimension is impacted to different degrees, highlighting

the multifaceted benefits of integrating these activities into formal and informal contexts. The participatory design approach employing the DPE framework in workshops provided valuable insights into design development. Furthermore, it facilitated the exploration of relationships and the recognition of patterns between the topic, the game scene, and the participants. The board game design process allowed addressing critical ocean literacy dimensions to be worked in a playful and impacting manner in the teaching setting. In particular, the experiment with the AR game board was shown to have the potential to positively affect the students' knowledge, awareness, communication, attitude, activism and behaviour dimensions. The game aesthetics, challenges, fantasy, curiosity and interactivity features can nurture feelings of pleasure and seem to have the potential to engage people in these different ocean literacy dimensions. Aesthetics and functionality together can promote more substantial engagement results. These findings are important to design environmental information to inform, engage people with the topic, and promote action. The research findings reveal a significant correlation among several dimensions, which became more pronounced following gameplay. This suggests a need to foster a holistic understanding of ocean information design rather than examining the dimensions in isolation. The insights gained from this research are relevant to the research and development of more engaging educational resources. Additionally, they can enhance knowledge, awareness and communication regarding ocean-related topics, ultimately fostering informed and responsible decision-making.

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Data availability Data will made available on request.

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

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