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Past Shipwrecks

[Fernando Angelino]

③

IMMERSIVE OCEANS

Leveraging Virtual and Augmented Reality to Advance Ocean Literacy

The San Pedro de Alcántara shipwreck as represented in late 18th-century drawings, engravings and paintings

Immersive Oceans

Future Shipwrecks

[Célia Quico]

LEVERAGING VIRTUAL AND AUGMENTED REALITY TO ADVANCE OCEAN LITERACY



[FERNANDO ANGELINO]

[Fernando Angelino]
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Immersive Oceans
Future Shipwrecks

ABSTRACT

This work explores the integration of immersive technologies, such as Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Artificial Intelligence (AI), to enhance ocean literacy education across all levels of schooling. By leveraging these innovative tools, educators can create engaging, experiential learning environments that foster critical thinking, collaboration, and a deeper understanding of marine ecosystems.

The insights gathered highlight the importance of accessibility, curriculum integration, and user-friendly design, while emphasizing the need for teacher training and community engagement. This approach not only motivates students but also equips them with the knowledge and skills necessary to address pressing ocean-related challenges.This work advocates for ongoing research and evaluation to continuously improve the effectiveness of immersive technologies in promoting ocean literacy.

Keywords: Ocean Literacy, Immersive Technologies, Experiential Learning, Curriculum Integration

INTRODUCTION

In an era where the health of our oceans is increasingly threatened by climate change, pollution, and overfishing, fostering ocean literacy among students and future generations has never been more critical. Ocean literacy—the understanding of the ocean's influence on us and our influence on the ocean—serves as a foundation for informed decision-making and responsible stewardship of marine resources.

This chapter explores the transformative potential of immersive technologies, including Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Artificial Intelligence (AI), in promoting ocean literacy across diverse educational settings.

As traditional teaching methods often struggle to engage students in complex environmental issues, immersive technologies offer innovative solutions that create interactive and experiential learning environments. By simulating real-world marine ecosystems and challenges, these technologies not only captivate students' attention but also enhance their critical thinking and problem-solving skills. This chapter synthesizes insights from recent research, highlighting the importance of accessibility, curriculum integration, and user-friendly design in the effective implementation of these tools.

THE URGENCY OF OCEAN LITERACY IN THE DIGITAL AGE

Various types of literacy, such as science literacy, digital literacy, environmental literacy or ocean literacy point to skills that are essential in our time, and that goes beyond reading and writing in the classical sense.

Ocean literacy is increasingly recognized as a critical component in addressing global environmental challenges, particularly in the digital age. Ocean literacy is crucial for achieving global commitments to sustainable development by 2030 and beyond. It is essential for catalysing behaviour changes necessary for a sustainable future (Glithero et al., 2025; Kelly et al., 2022a). Ocean literacy is conceptualized as a multidimensional construct encompassing the awareness, knowledge, and behavioral intentions necessary to foster sustainable human-ocean interactions (Wang et al., 2025)

It encompasses the understanding of how human actions impact the ocean and vice versa. This understanding is vital for fostering sustainable behaviours and policies that protect marine ecosystems. The urgency for ocean literacy is underscored by pressing issues such as climate change, biodiversity loss, and pollution. These challenges necessitate a well-informed public that can advocate for sustainable ocean management (Kelly et al., 2022a; McCauley et al., 2021). Engaging diverse populations, especially in urban areas where direct interaction with the ocean is limited, is crucial. Strategies must be developed to enhance societal connections to the ocean, which can catalyze behaviour changes necessary for sustainability (Kelly et al., 2022a; McRuer et al., 2025).

The integration of ocean literacy into educational systems is critical for fostering a collective understanding of marine ecosystems' vulnerability and the urgency of their protection and this is particularly important for coastal communities that rely on these ecosystems for their livelihoods (González et al., 2026; Mokos et al., 2020). The urgency of ocean literacy is evident in the need for transformative communication and training tools that can effectively engage ocean citizens from all backgrounds in co-designing ocean sustainability pathways. Extended Reality (XR) immersive technologies like Virtual Reality (VR) and Augmented Reality (AR) are powerful tools for enhancing ocean literacy. They provide engaging, interactive experiences that can make complex oceanic concepts accessible and relatable. These technologies facilitate experiential learning, allowing users to explore marine environments virtually. This can enhance emotional connections to the ocean and motivate individuals to act for its conservation (Hetherington et al., 2026a).

[Fernando Angelino]
Leveraging Virtual and Augmented Reality to Advance Ocean Literacy
Immersive Oceans
Future Shipwrecks

These technologies offer unique opportunities to engage learners in interactive and experiential learning, which is crucial for understanding complex marine environments and fostering a connection to the ocean. Immersive technologies, such as VR, AR, and Mixed Reality (MR) create engaging and interactive learning experiences that can significantly enhance student interest and motivation. For example, VR-based learning systems allow students to explore underwater environments in 3D, which can be both educational and motivational (Chen et al., 2026; Ikramov et al., 2025). AR games have also been shown to increase awareness and willingness to participate in marine conservation efforts, indicating their potential to complement traditional educational methods (Cifra et al., 2025).

OCEAN LITERACY, EXPERIENTIAL LEARNING, AND IMMERSION

Ocean literacy must be framed as a strategic global challenge that requires collaboration across nations and disciplines. The interconnectedness of ocean health with climate change and public health emphasizes the need for a unified approach. Effective ocean literacy initiatives should integrate insights from various fields, including marine science, psychology, and education. This transdisciplinary approach can help address the diverse dimensions of human-ocean relationships and promote effective policymaking.

Ocean literacy can serve as a policy mechanism to align with global sustainability goals, such as the United Nations Sustainable Development Goals (SDGs). By embedding ocean literacy into educational frameworks and public policy, stakeholders can enhance community resilience and promote sustainable practices (Glithero et al., 2025; Husna et al., 2024; McRuer et al., 2025; Scowcroft et al., 2021).

Referring to some foundational and conceptual works about ocean literacy, the existence of the International Ocean Literacy Survey (OLS) which measures ocean knowledge across the world, already translated into 17 languages and tested in 24 countries is one significant tool to address the ocean literacy status. Psychometric analyses show that IOLS is a valid and reliable instrument that measures a single factor - ocean literacy (Fauville et al., 2019).

The United Nations Ocean Decade Ten Goals and Challenges[1], the Unesco Ocean Literacy seven Principles Framework[1] and, the National Oceanic and Atmospheric Administration (NOAA) seven Essential Principles of Ocean Literacy Framework[3], are considered among the most relevant organizations in the education and conservation of the ocean and ocean literacy areas.

(1) https://oceandecade.org/
(2) https://oceanliteracy.unesco.org/
(3) https://oceanservice.noaa.gov/

Regarding the evolution of the concept of ocean literacy, which has gained increasing recognition as a mechanism for change within the United Nations Ocean Decade's goals, McKinley et al., (2023) propose a new framework with ten dimensions of ocean literacy. In their work, Glithero et al. (2025); Kelly et al. (2022b) discuss the importance of improving public understanding of the ocean and sustainable ocean use, known as "ocean literacy", to achieve global commitments to sustainable development by 2030 and beyond. They identify four key drivers that can also influence and improve ocean literacy: (1) education, (2) cultural connections, (3) technological developments, and (4) knowledge exchange and science-policy interconnections. The authors present an "ocean literacy toolkit" that provides a practical framework for enhancing ocean connections across diverse contexts worldwide. The toolkit includes best practice principles, a design and implementation framework, and examples of successful ocean literacy initiatives.

Online educational platforms, including MOOCs (Massive Open Online Courses), have emerged as effective means to democratize ocean literacy. They can reach a global audience, fostering awareness and engagement with marine issues. For instance, the "Exploring Our Oceans" MOOC has successfully engaged thousands of participants worldwide, demonstrating the potential of digital learning environments (Fielding et al., 2019).

Immersive technologies, particularly virtual reality (VR) and augmented reality (AR), are also playing a transformative role in enhancing ocean literacy initiatives globally. These technologies provide engaging, interactive experiences that can significantly improve understanding and attitudes towards ocean conservation and sustainability among diverse audiences. AR and VR cater to various learning preferences, making complex subjects more approachable. They facilitate hands-on practice in simulated environments, which is particularly beneficial in educational settings where traditional methods may fall short (Klippel et al., 2025a; Varpe et al., 2026a).

Integrating ocean literacy into educational curricula is essential for fostering a generation that values and understands the ocean. This includes developing resources that are culturally relevant and accessible to diverse audiences. Practical contributions also involve creating participatory initiatives that engage local communities in ocean conservation efforts. This can help bridge the gap between scientific knowledge and community action, ensuring that ocean literacy is not just theoretical but actionable (McCauley et al., 2021; Nicola et al., 2025a).

[Fernando Angelino]
Leveraging Virtual and Augmented Reality to Advance Ocean Literacy
Immersive Oceans
Future Shipwrecks

VR/AR ARE PARTICULARLY POWERFUL FOR OCEAN EDUCATION

Ocean education often involves complex and abstract concepts. VR and AR can visually depict these concepts, making them easier to understand. For example, students can explore underwater ecosystems, observe marine life, and understand oceanic processes in a highly interactive manner, allowing students to experience the ocean in a way that traditional methods cannot, making learning more captivating and enjoyable (Kononov et al., 2025; Spivey et al., 2025; Vashisht, 2024). VR and AR enable students to engage in hands-on practice through simulations and interactive experiences. This is particularly useful in ocean education, where real-world field trips can be logistically challenging and expensive. These technologies also provide a safe environment for students to conduct experiments and explore the ocean without the risks associated with real-life underwater activities (Naqvi et al., 2024; Varpe et al., 2026b).

Immersive media, particularly AR, can bridge the gap between distant environmental issues and learners by providing experiential marine environmental education. VR simulations, such as underwater virtual reality field trips, enable learners to experience marine environments without physical presence, enhancing their understanding of marine ecosystems and environmental dynamics. For instance, platforms like V-CURRENTS offer underwater virtual reality field trips, making the ocean accessible to learners who might otherwise have limited exposure to marine environments (Ikramov et al., 2025; Klippel et al., 2025a).

Rigorous experimental research demonstrates that XR technologies produce measurable learning outcomes and behavioural changes related to ocean literacy. The study by Markowitz et al. (2018) tested immersive VR with over 270 participants across four different learning settings, showing that people consistently demonstrated knowledge gains about ocean acidification and climate science after experiencing virtual underwater worlds. This research is particularly significant because it validated learning effects across diverse participant groups including high school students, college students, and adults, using multiple assessment measures from learning gain scores to qualitative teacher feedback.

Research indicates that immersive learning tools can significantly increase knowledge acquisition and awareness of ocean-related issues. The immersive and interactive nature of VR and AR has been shown to improve knowledge retention and comprehension. Students are more likely to remember what they have learned when they can interact with the material in a meaningful way. These technologies foster the development of critical thinking, problem-solving, and collaborative skills which are essential for understanding and addressing complex environmental issues related to the ocean (Ali et al., 2022).

For example, a study involving an AR game-based educational tool demonstrated substantial improvements in students' understanding ocean literacy dimensions, including knowledge, awareness, and activism (Leitão et al., 2025). Programs that integrate immersive technologies have shown to revitalize student interest and engagement in ocean literacy topics. For instance, a project in Brazil that combined theoretical lessons with hands-on activities resulted in improved student attitudes and a deeper connection to local marine environments (Pazoto et al., 2023). VR and AR can also make the ocean accessible to students who may not have the opportunity to experience it in person. This is particularly important for students in landlocked areas or those with physical limitations by addressing challenges related to accessibility in ocean education. These technologies can provide diverse learner populations with equal opportunities to engage with marine content, regardless of their geographical location or physical abilities. The above-mentioned technologies can enhance students' awareness of sustainability issues and the importance of ocean conservation.

By immersing students in virtual ocean environments, they can develop a deeper understanding and appreciation of marine ecosystems (Zekeik et al., 2026a). VR experiences, such as Underwater Virtual Reality (UVR), create high levels of presence and emotional engagement, which can trigger powerful emotions like awe and empathy. This emotional connection can improve ocean literacy by making marine environmental issues more relatable and urgent, and VR diving experiences also allow students to observe marine life and ecological issues firsthand, increasing their motivation to learn about and protect the ocean (Fauville et al., 2024).

Immersive technologies can be systematically integrated into existing ocean literacy curricula. A conceptual framework has been proposed by Muktiarni et al (2025) to embed VR and AR into vocational education, particularly in tourism, aligning with Sustainable Development Goals (SDGs). This framework emphasizes the need for curricula to include ocean-related competencies and immersive tools. Several of these tools facilitate collaboration and dialogue among learners, although challenges such as the lack of real-time interaction need to be addressed and platforms like the Iliad Academy provide comprehensive resources and training on digital ocean technologies, fostering interdisciplinary collaboration and knowledge-sharing (Hetherington et al., 2026a; Shahinyan & Kazanjian, 2025).

Research shows that XR technologies effectively improve ocean literacy by increasing knowledge gains, strengthening environmental attitudes, and enhancing donations to conservation causes. Studies reveal that the more students explore virtual marine environments, the better they learn complex concepts like ocean acidification.

However, researchers note that understanding XR learning outcomes requires examining multiple aspects of the technology rather than individual components in isolation. This suggests that future research should take more holistic approaches when evaluating the effectiveness of XR interventions for ocean literacy, considering how different technological elements work together to produce learning outcomes (Aguayo et al., 2023).

[Fernando Angelino]
Leveraging Virtual and Augmented Reality to Advance Ocean Literacy
Immersive Oceans
Future Shipwrecks

APPLICATIONS OF VR IN OCEAN LITERACY

VR technologies are increasingly being integrated into ocean literacy education, enhancing student engagement and understanding of marine ecosystems. In this section, a summary of VR projects and technologies is listed regarding their implementation in educational settings, and their main goals and outcomes.

Immersive VR platforms such as V-CURRENTS, CoSpaces EDU, UVR, VR-Ocstal, and VREX are effectively utilized for teaching ocean literacy. These platforms offer engaging, realistic, and interactive experiences that enhance learning and foster a deeper connection to marine environments. However, the integration of these technologies requires careful consideration of teacher involvement and the emotional impact on learners. Some of the additional key findings and benefits of the above technologies and projects are an improvement in engagement and learning, a relevant emotional and psychological impact, and stronger collaborative learning.

To enhance ocean literacy education in schools, several innovative immersive technologies can also be utilized. These key technologies provide engaging, interactive, and effective learning environments that can significantly improve students' understanding and appreciation of marine ecosystems, such as underwater VR experiences, AR game-based learning, among others.

VR and AR are powerful tools for enhancing ocean literacy education in schools. However, challenges such as technological limitations, lack of teacher training, and funding issues must be addressed to fully realize their potential. By integrating gamification techniques, problem-based learning (PBL) or inquiry-based learning (IBL), which foster collaborative learning environments, educators can create a more dynamic and impactful ocean literacy curriculum that prepares students to engage with global conservation efforts effectively.

CHALLENGES AND LIMITATIONS

Implementing immersive technologies such as VR, AR, and MR in education, particularly for ocean literacy, presents several challenges and limitations. The integration of extended reality into educational frameworks offers a ground-breaking approach to deepening the public's understanding of marine ecosystems and their critical role in planetary health. These can be broadly categorized into technological, financial, pedagogical, and contextual barriers.

TECHNOLOGICAL CHALLENGES

The integration of immersive technologies requires significant technical knowledge and expertise, which can be a barrier for educators who may not be proficient in these technologies. Also, many educational institutions, especially in developing countries, face infrastructure limitations and lack the necessary infrastructure to support immersive technologies. Effective use of VR often requires robust internet connectivity, which can be a significant barrier in many educational settings, especially in rural or underdeveloped areas. Limited bandwidth can restrict the use of high-quality VR applications, leading to a subpar educational experience (Mondal & Mondal, 2025; Yadav, 2025). Content availability might also be a problem since a lack of localized and relevant content that aligns with the curriculum, makes it difficult for educators to effectively integrate these technologies into their teaching practices (Msweli & Kgopa, 2025).

FINANCIAL CHALLENGES

The initial investment for VR technology can be substantial, which includes the cost of headsets, computers, and other necessary hardware. This financial barrier is particularly pronounced in resource-constrained environments, where schools may struggle to afford such technology (Zekeik et al., 2026b). To develop and scale immersive technology solutions to be sustainable over the long term is also challenging due to the high initial investment and ongoing maintenance costs (Bosman et al., 2024; Mondal & Mondal, 2025). Several socio-economic disparities significantly influence the accessibility and adoption of immersive technologies in education. In resource-constrained environments, high costs, limited access to technology, and socio-cultural resistance can impede the integration of AR and VR. These factors vary across regions, with developing countries facing more pronounced challenges compared to developed nations (Mondal & Mondal, 2025). In some cases, institutional resistance to change and a lack of strategic investment in technology can further complicate the adoption of immersive learning tools. Effective implementation requires not only financial resources but also a supportive policy environment that encourages innovation in teaching practices (Cabero-Almenara et al., 2026; Msweli & Kgopa, 2025).

[Fernando Angelino]
Leveraging Virtual and Augmented Reality to Advance Ocean Literacy
Immersive Oceans
Future Shipwrecks

PEDAGOGICAL CHALLENGES

A significant barrier is the lack of adequate training for educators. Many teachers feel unprepared to integrate these technologies into their teaching practices due to insufficient professional development opportunities. Effective use of immersive technologies requires comprehensive teacher training and ongoing professional development to ensure educators are comfortable and proficient in using these tools. Current knowledge shows that immersive technologies need to be carefully integrated into the curriculum to ensure they meet educational objectives and enhance learning outcomes. This requires thoughtful instructional design and alignment with pedagogical goals. To effectively incorporate immersive technologies, pedagogical frameworks must also evolve. Current curricula often do not systematically integrate ocean-related competencies or immersive tools, necessitating the development of new models that link technology with knowledge, skills, and sustainability values. Educators need to adopt flexible, multi-tiered training frameworks that cater to varying levels of experience among teachers (Izouaouen et al., 2025; Muktiarni et al., 2025). The development of robust methodologies to evaluate the effectiveness of immersive technologies in achieving learning outcomes is also essential. This includes assessing user satisfaction, motivation, and learning progress (Law et al., 2008; Mamadiyarov et al., 2025; Mendoza et al., 2023).

CONTEXTUAL CHALLENGES

One of the unique challenges in ocean literacy is making distant and often abstract oceanic issues relatable and engaging for students. Immersive technologies can help bridge this gap, but their effectiveness depends on how well they are integrated into the learning experience. Ensuring that all students, regardless of their background, have equitable access to immersive learning experiences is crucial. This includes addressing the digital divide and ensuring that marginalized groups are not left behind (Klippel et al., 2025b; Nicola et al., 2025b). The complexity of virtual environments can be overwhelming, leading to disengagement if not managed properly. Educators must be aware of these potential challenges and design experiences that are both engaging and manageable for learners. An effective usage of VR in ocean literacy education also depends on the availability of localized content that resonates with students' experiences and environments. The absence of such content can limit the relevance and impact of VR applications. (Ndjama & van der Westhuizen, 2024). Immersive experiences can foster a deeper connection to ocean literacy by allowing students to explore underwater environments virtually. However, educators need to ensure that these experiences are meaningful and relevant to students' lives to maintain motivation and interest (Hetherington et al., 2026b; Ikramov et al., 2025).

While immersive technologies hold great potential for enhancing ocean literacy education, addressing the technological barriers, adapting pedagogical frameworks, considering socio-economic factors, and understanding psychological challenges are crucial for successful implementation. By strategically overcoming these challenges (high costs, hardware and software limitations, internet connectivity issues, and the necessity for comprehensive teacher training), educators can create more engaging and effective learning experiences that promote a deeper understanding of ocean ecosystems and sustainability.

CONCLUSION AND RECOMMENDATIONS

The effective promotion of ocean literacy through immersive technologies requires considerable access to technological infrastructures, specialized educational content and software, a pedagogical redesign and training, supported by significant collaboration and an interdisciplinary approach.

To effectively promote ocean literacy through immersive technologies, several recommendations can also be made. These suggestions aim to address the challenges and barriers identified earlier, ensuring that educators and students can fully benefit from the potential of immersive technologies.

Encourage educational institutions to apply for grants and funding from government agencies, NGOs, and private organizations dedicated to educational technology and environmental education and develop partnerships between schools, local governments, and businesses to share the costs of acquiring and maintaining immersive technology resources.

Invest in improving internet connectivity and technological resources in schools, particularly in underserved areas, to ensure that all students have access to immersive technologies and establish dedicated VR labs in schools or community centres where students can access immersive technologies without the need for individual ownership.

Collaborate with marine scientists, educators, and content creators to develop localized and contextually relevant VR content that aligns with ocean literacy goals and curriculum standards. Promote the creation and sharing of open-source VR educational materials that can be adapted and used by educators worldwide.

Implement ongoing professional development programs that equip educators with the skills and knowledge to effectively integrate immersive technologies into their teaching practices. Foster communities of practice where educators can share experiences, resources, and best practices related to the use of immersive technologies in ocean literacy education and ensure that VR applications are designed with usability in mind, minimizing technical barriers and cognitive load for students. Also develop immersive technologies that are accessible to all students, including those with disabilities, to ensure equitable learning opportunities.

[Fernando Angelino]
Leveraging Virtual and Augmented Reality to Advance Ocean Literacy
Immersive Oceans
Future Shipwrecks

Organize community events, workshops, and campaigns to raise awareness about ocean literacy and the role of immersive technologies in education to engage parents, local communities, and marine organizations in the development and implementation of immersive technology initiatives to foster a collaborative approach to ocean literacy.

Develop robust methodologies to evaluate the effectiveness of immersive technologies in achieving learning outcomes related to ocean literacy and collect feedback from students and educators to continuously improve the immersive learning experience and address any challenges that may arise.

Support research initiatives that explore the most effective ways to integrate immersive technologies into ocean literacy education, including case studies and pilot programs while encouraging the development of new immersive technologies and applications that specifically target ocean literacy and environmental education.

The observation of some of these recommendations by educational institutions could help to promote a supportive environment for the integration of immersive technologies, ultimately enhancing ocean literacy and fostering a deeper understanding of marine ecosystems among students.

All the oceans and maritime environments in general will appreciate and be grateful for all efforts developed in this regard!

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