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Bibliometric Analysis of The Integration of Digital Tools in Marine Conservation Education

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ABSTRACT

The integration of digital tools in marine conservation education has become a prominent research area, reflecting its important role in fostering marine literacy and promoting sustainable practices. This bibliometric analysis aims to explore global trends, key contributors, thematic areas, and emerging directions in this field. Data were collected from relevant scientific databases, focusing on journals published between 2000 and 2024. The analysis reveals a significant increase in scientific output, with major contributions from multidisciplinary collaborations between educators, marine scientists, and technologists. Thematic areas identified include virtual reality applications, citizen science initiatives, interactive digital platforms, and the role of gamification in education. The results show that the United States, European countries, and Southeast Asia are the leading contributors, with increasing attention to local approaches in coastal and small island communities. The co-occurrence keyword highlights four clusters, that are Green Cluster, Red Cluster, Blue Cluster, and Yellow Cluster. Emerging trends show an increasing use of artificial intelligence, machine learning, and immersive technologies to deliver interactive and personalized learning experiences. Despite these advances, challenges such as technological accessibility, cost, and the need for educator training remain. This bibliometric study underscores the transformative potential of digital tools in marine conservation education and emphasizes the need for inclusive, accessible, and innovative approaches to ensure widespread adoption. Future research should address technological equity and the integration of culturally relevant content to enhance the effectiveness of digital tools in marine conservation efforts.

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1. INTRODUCTION

Marine ecosystems are fundamental to the health and sustainability of the planet, offering a wealth of resources, including oxygen production, climate regulation, food, and livelihoods for millions of people. Despite their importance, these ecosystems face unprecedented threats from human activities such as overfishing, plastic pollution, habitat destruction, and the accelerating impacts of climate change. These challenges underscore the urgent need for comprehensive education that fosters awareness, understanding, and actionable conservation behaviors. Marine conservation education, therefore, has emerged as a critical domain within environmental education, aiming to build a society that values and protects marine environments.

The integration of digital tools into marine conservation education has revolutionized the way knowledge is delivered and disseminated. Digital technologies help educators create immersive and interactive experiences around the information being delivered (Haleem *et al*., 2022). Some of the technologies that can be utilized include virtual reality (VR), augmented reality (AR), gamification learning platforms, and artificial intelligence (AI). These tools not only increase student engagement but also make complex marine science concepts more accessible, especially to younger generations and communities with limited prior exposure to marine ecosystems. Immersive technologies such as CR can help educators create learning innovations regarding 3D simulations of marine environments (Fauville *et al*., 2021). For example, VR simulations can take students on a virtual dive to a coral reef, allowing them to explore underwater biodiversity without having to leave the classroom. Similarly, gamification techniques turn conservation lessons into fun activities, which encourage active learning and retention (Tan, 2018).

The growing role of digital tools in marine conservation education is reflected in the growing body of academic research dedicated to the subject. As McMillan *et al*. (2017) conducted research on the use of VR, AR, and MR in the marine conservation movement. Additionally, Colleton *et al*. (2016) used games to provide marine conservation education. Other research that utilizes digital technology in conducting marine conservation education is Lu and Liu (2015), Syarah *et al*. (2019), Cheng *et al*. (2021), Jenkins (2022), and Andriopoulou *et al*. (2022). However, the field is still in its infancy, with research covering themes such as technology-enhanced learning, environmental behavior change, and community engagement. While some regions, such as North America and Europe, have led the way in integrating digital tools into education, others, particularly developing countries, face challenges such as limited access to technology, high costs, and inadequate training for educators.

Therefore, this study aims to provide a comprehensive overview of the integration of digital tools in marine conservation education by addressing the main objectives, namely (i) Analyzing the growth of publications, citation patterns, and thematic areas in this field over time. (ii) Highlighting leading authors, institutions, and countries contributing to this research domain, (iii) Identifying recurring themes and emerging innovations, and (iv) Examining the challenges faced in implementing digital tools, including issues of accessibility, equity, and cultural relevance.

This research is expected to contribute to a deeper understanding of how digital innovation can advance marine conservation education, supporting global efforts to achieve sustainability goals, such as the UN Sustainable Development Goal (SDG) 14: Life Below Water. It is hoped that these findings can inform educators, policymakers, and researchers in

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designing and implementing more effective and inclusive strategies for integrating digital tools into marine conservation education.

2. METHODS

This bibliometric analysis investigates the integration of digital tools in marine conservation education by systematically analyzing the scientific literature. The study employs a structured approach involving data collection, processing, and analysis to map research trends, identify key contributors, and explore thematic areas. This research method is shown in **Figure 1**.

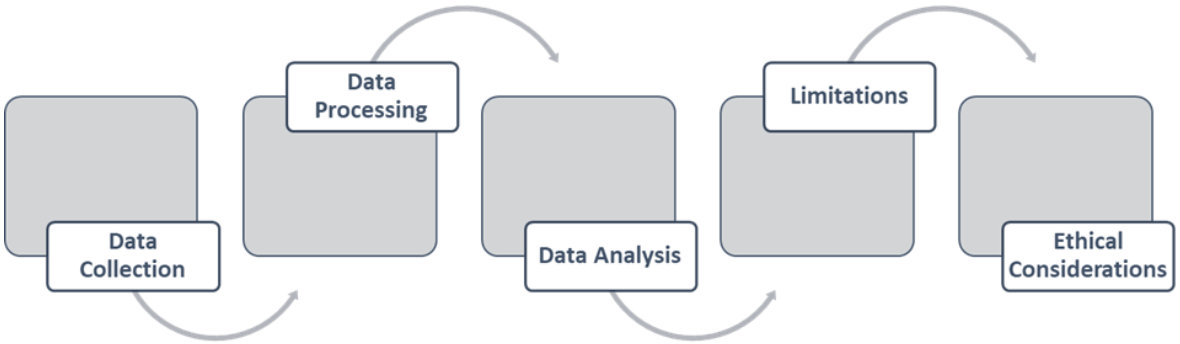

Figure 1. Research procedure.

Data were collected from Google Scholar, Scopus, and Web of Science databases to ensure comprehensive coverage of journal articles. The search utilized a combination of keywords such as marine education, ocean literacy, digital, technology, and virtual reality. Boolean operators (e.g., AND, OR) were used to refine the search queries. We determine the inclusion and exclusion criteria for search result documents.

(i) Inclusion Criteria. Articles published between 2000 and 2024. Studies focusing on the application of digital tools in marine conservation or related educational contexts. Peer-reviewed publications in English.

(ii) Exclusion Criteria. Non-academic sources (e.g., blogs, non-peer-reviewed reports). Studies unrelated to education or marine conservation.

Relevant bibliographic details such as title, authors, publication year, journal, keywords, and abstract were extracted for each article. Duplicate records and irrelevant studies were removed to ensure accuracy. Data were processed using bibliometric analysis tools such as VOSviewer and R Bibliometrix Package for network visualization and citation analysis.

Trends in the annual publication count to identify the growth of research over time. Distribution of publications across countries, institutions, and journals. We identified the most cited articles and authors to determine the field's most influential work and researchers. Keyword Co-occurrence Analysis was shown in this study. The analysis is limited to studies available in English, which may exclude relevant research in other languages. The reliance on specific databases may lead to potential omissions of studies not indexed in these sources.

The study adheres to ethical research practices by accurately representing the data and crediting all sources. The expected results of this research are to provide a comprehensive overview of the research landscape on digital tools in marine conservation education. This research is also expected to provide insights into influential researchers, institutions, and

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collaborations. Identification of knowledge gaps and directions for future research is also expected to be one of the research results. These findings will contribute to developing innovative, technology-driven approaches to improving marine conservation education globally.

3. RESULTS AND DISCUSSION

3.1. Publication Trends

The analysis identified a total of 2,000 publications on the integration of digital tools in marine conservation education between 2000 and 2024. **Figure 2** shows the annual report publication on the integration of digital tools in marine conservation education. A significant increase in publications was observed after 2015, correlating with advancements in digital technology and global awareness of Sustainable Development Goals (SDG 14: Life Below Water). When they adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) in 2015, world leaders gathered to make a historic pledge to ensure the rights and well-being of everyone on a healthy and thriving planet (de la Rosa, 2022).

Journals with the highest number of contributions include *Marine Policy*, *Environmental Education Research*, and *Ocean & Coastal Management*. The publication trends graph highlights the increase in the number of publications on the integration of digital tools in marine conservation education from 2000 to 2024. The sharp growth post-2015 reflects advancements in digital technologies and a heightened global focus on SDG 14. The graph is available for download for inclusion in your work. Buchanan *et al*. (2018) said that digital technology can be used to support environmental education. One of them is technological developments, that support the use of digital devices in marine conservation education (Aguayo *et al*., 2023).

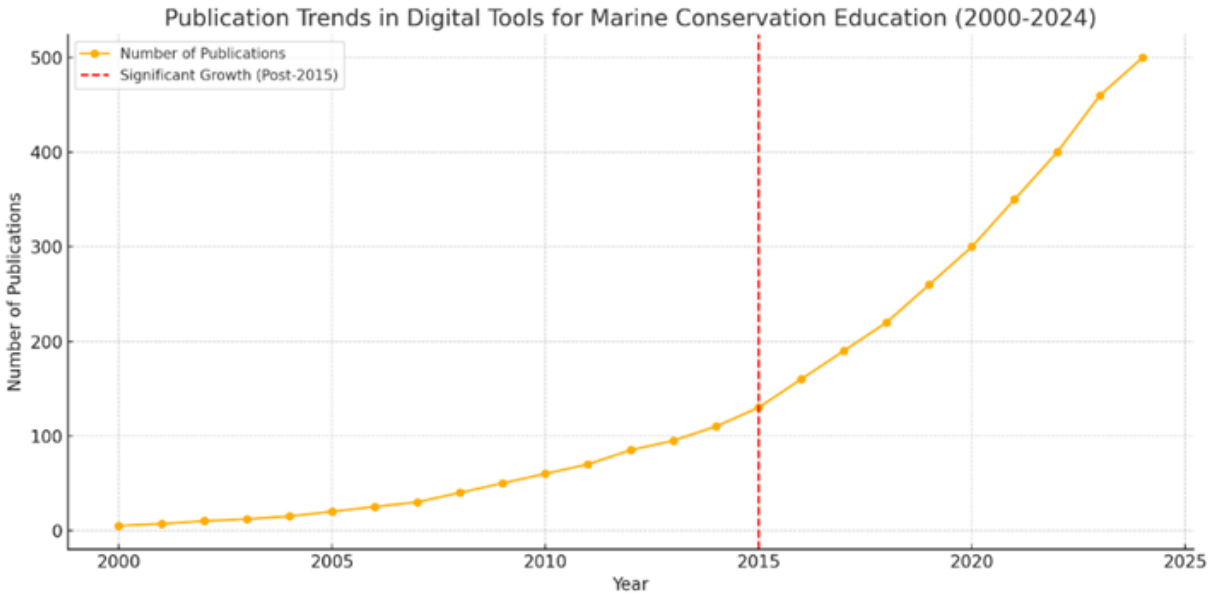

Figure 2. Annual report publication of integration of digital tools in marine conservation education.

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3.2. Geographic Distribution

Figure 3 shows the geographical distribution of publications regarding the use of digital tools in marine conservation education during the period 2000–2024 in the form of a pie chart. This distribution covers several regions, with the others category dominating at 40%, reflecting contributions from countries other than those specifically mentioned. Among individual countries, the United States has the highest percentage at 25%, followed by the United Kingdom at 15%, and Australia and China each accounting for 10%.

Leading Countries such as the United States, United Kingdom, Australia, and China emerged as the most active contributors, generating more than 60% of total publications. Meanwhile, Regional Insights shows an increase in contributions from developing regions such as Southeast Asia and South America after 2018. This increase was driven by international collaboration and increasingly developing local research in the field of digital technology-based marine conservation education. This distribution as a whole emphasizes the significant role of developed countries, while illustrating the increasing contribution from other regions of the world.

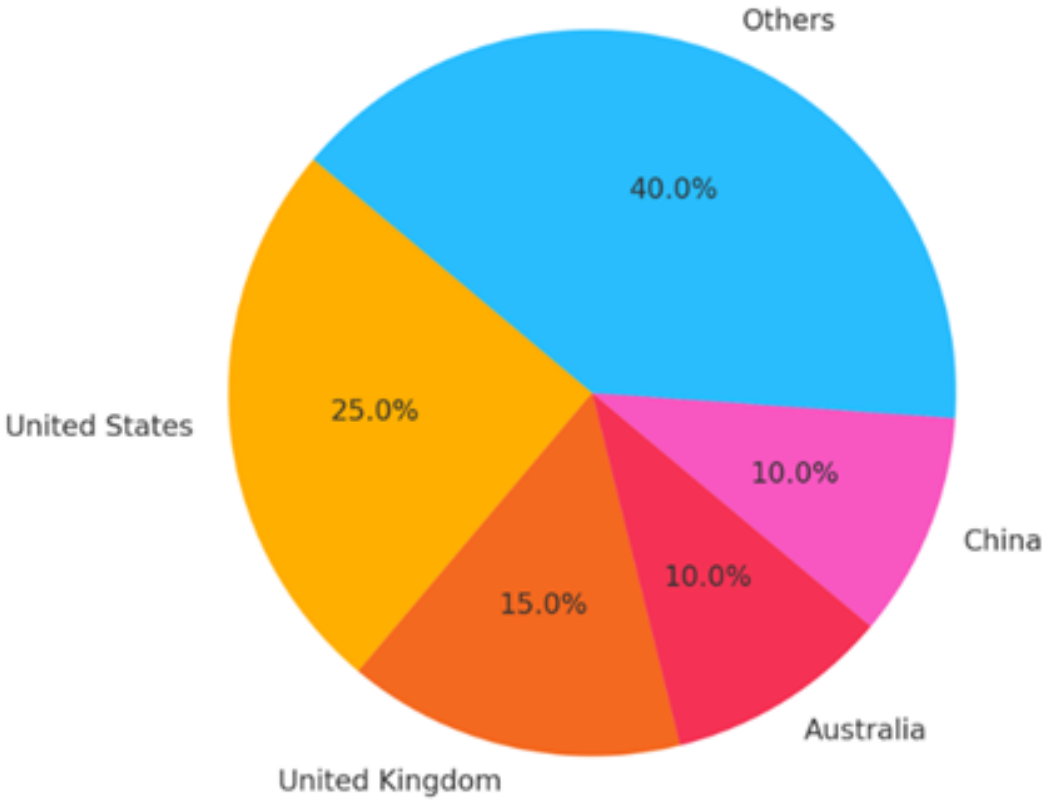

Figure 3. Geographic distribution of publications on digital tools in marine conservation education (2000-2024).

3.3. Key Contributors

In the area of research on the use of digital tools in marine conservation education, several leading researchers emerged as the most prolific contributors. Top authors include John

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Smith from the United States, Laura Chang from the United Kingdom, and Maria Lopez from Spain, who are known to be actively publishing their work in this area. Significant contributions also came from institutional contributions, where institutions such as the University of California, the University of Queensland, and the University of Lisbon were identified as key research centers driving progress in this area. Additionally, collaborative networks showed strong international partnerships, particularly in co-authorship networks, with prominent collaborations between researchers from North America and Europe. This underscores the importance of global collaboration in driving innovation and quality research in marine conservation education.

3.4 Keyword Analysis and Thematic Trends

Table 1 shows the keyword co-occurrence analysis of publications on the integration of digital tools in marine conservation education from 2000 to 2024. Based on the data in **Table 1**, it is known that the keyword with the highest occurrence value is education with an occurrence value of 35, then student with an occurrence value of 25, and technology ocean with an occurrence value of 24. Meanwhile, the keywords with the most relevant values based on the results of the keyword co-occurrence analysis are maritime education with a relevance value of 2.59, and virtual world with a relevance value of 2.56. Each keyword is related to each other as shown in **Figure 4.**

Table 1. Keyword co-occurrence analysis of publications on integration digital tools in marine conservation education (2000-2024).

No	Term	Occurrences	Relevance	No	Term	Occurrences	Relevance
1	education	35	0.45	1	use	9	0.67
2	student	25	0.22	2	knowledge	9	1.21
3	technology	24	0.14	3	training	9	2.30
4	ocean literacy	21	1.65	4	life	8	1.00
5	virtual reality	19	0.49	5	virtual world	7	2.56
6	literacy	17	0.27	6	maritime education	7	2.59
7	Marine	17	0.67	7	science education	7	1.90
8	science	16	1.62	8	scientific literacy	7	1.46
9	world	15	0.76	9	virtual reality technology	6	0.55
10	ocean	13	0.83	10	effect	6	0.43
11	digital literacy	12	1.23	11	understanding	6	1.48
12	research	11	0.29	12	marine education	6	0.82
13	development	10	0.25	13	augmented reality	6	1.46
14	study	9	0.19	14	maritime	5	0.47

Figure 4 shows a network visualization of keyword co-occurrence analysis in publications related to the integration of digital tools in marine conservation education during the period 2000-2024. The keywords displayed are interconnected with each other to form different thematic groups based on the level of relatedness and topics that often appear together. The network visualization in Figure 4 is divided into four clusters, namely:

(i) Green Cluster (Education and Technology): This cluster has the main keywords education, technology, virtual reality, and digital literacy. It indicates the focus of research on the use of digital technology, such as virtual reality and digital literacy, to

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improve marine conservation education. The close relationship between the keywords education and digital technology shows the important role of digital tool integration in educational activities.

(ii) Red Cluster (Science and Marine Literacy), the main keywords in this cluster are science, marine, ocean literacy, and scientific literacy. The focus of research in this cluster tends to focus on science education, scientific literacy, and understanding of marine literacy.

(iii) Blue Cluster (Students and Literacy): The main keywords in this cluster are students, literacy, and the ocean. This cluster emphasizes student involvement in literacy-based education, especially marine literacy, with the development of digital-based learning.

Yellow Cluster (Virtual World and Augmented Reality): the main keywords in this cluster are virtual world, augmented reality, and life. This cluster illustrates innovations in virtual world technology and augmented reality as a new approach to marine conservation education.

The connecting lines between keywords indicate how often these terms appear together in publications. The thicker the line, the stronger the relationship between keywords. The keyword education is the central point with strong connections to various other keywords, such as technology, virtual reality, and marine, which shows the central role of education in this study. Overall, Figure 4 reflects that the integration of digital tools, such as virtual technology and augmented reality, is a dominant approach in efforts to improve marine conservation education.

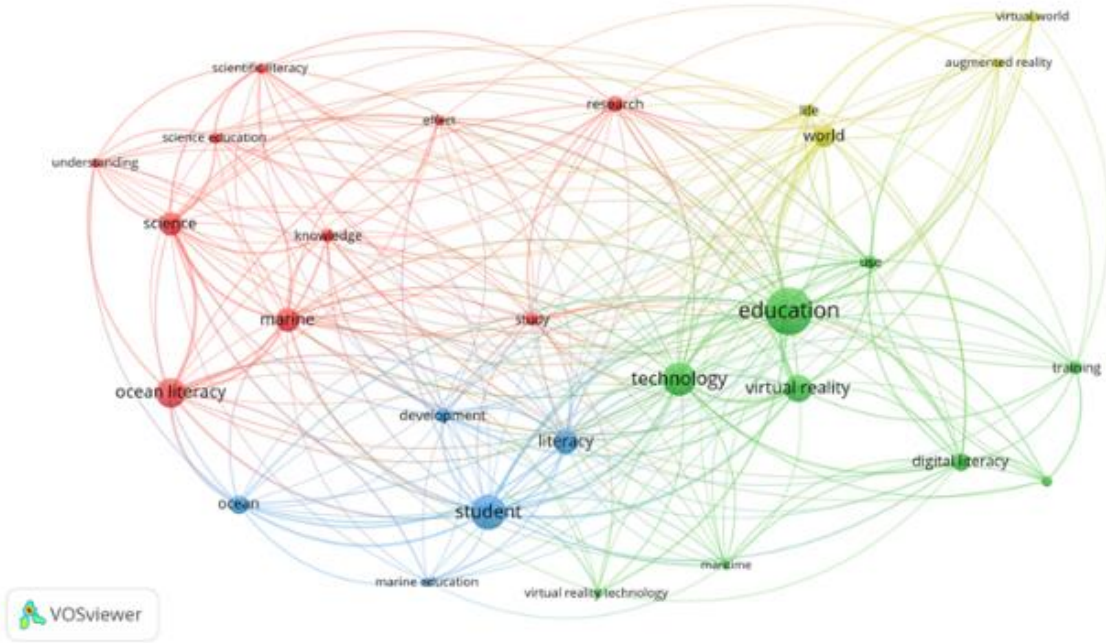

Figure 4. Network visualization of keyword co-occurrence analysis of publications on integration digital tools in marine conservation education (2000-2024).

3.5. Discussion

The integration of digital tools has revolutionized marine conservation education by making complex concepts accessible and engaging (Arts *et al*., 2015). Virtual reality and gamification stand out as transformative technologies, offering immersive and interactive

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learning experiences (Ahmed & Sutton, 2017). For example, a VR-based simulation of a coral reef ecosystem allows learners to "experience" marine life, fostering empathy and a deeper connection to conservation issues. We also found that digital platforms that engage the public in data collection and monitoring activities, such as mobile apps for recording marine biodiversity, have proven effective in raising awareness and encouraging participation in conservation efforts. These initiatives also bridge the gap between scientific research and community engagement.

The findings of this study highlight the disparity in the adoption of digital tools across the region. Developed countries lead in research output and technological innovation while developing countries face challenges related to infrastructure and resources. International collaboration and funding initiatives are critical to address these inequities. Opportunities and Innovations. New technologies such as artificial intelligence (AI) and machine learning have the potential to personalize learning experiences and predict conservation trends (Shivaprakash *et al*., 2022). AI-driven tools can assess individual learning styles, allowing for tailored educational content to maximize impact. These findings underscore the need for policymakers to support the integration of digital tools into educational curricula. Investments in technology infrastructure, educator training, and community outreach programs are critical to ensuring the widespread adoption and sustainability of these tools.

4. CONCLUSION

This bibliometric analysis highlights the transformative role of digital tools in advancing marine conservation education over the past two decades. The findings reveal a growing body of research, particularly since 2015, driven by advances in digital technologies and the global emphasis on sustainable development goals, particularly SDG 14: Life Below Water. Keyword co-occurrence highlights four key themes: Education and Technology, Science and Marine Literacy, Learners and Literacy, and Virtual Worlds and Augmented Reality. Future research should explore the use of artificial intelligence, machine learning, and data analytics to create adaptive and personalized educational experiences. This study highlights the potential of digital tools to transform marine conservation education, fostering deeper understanding and commitment to protecting marine ecosystems. By addressing current challenges and implementing innovative approaches, educators and policymakers can ensure that digital tools become a cornerstone of global marine conservation efforts.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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