Enhancing maritime education for ocean sustainability: a multidisciplinary approach

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Abstract. This research critically explores maritime education's role in fostering ocean sustainability and preparing seafarer students to tackle environmental challenges. It highlights the importance of marine science and technology literacy and proposes innovative solutions aligned with ocean health, resilience, and global climate change mitigation. Through qualitative descriptive analysis of select research papers, this study offers insights beneficial to the maritime industry and environmental conservation. The findings stress the need for curriculum enhancements, advocating for integrating marine science subjects and advanced technologies in maritime education. Proficiency in marine science and technology literacy is crucial for students to become competent professionals and responsible stewards of the marine environment. Green shipping practices, eco-friendly vessel design, and environmental bio-monitoring are identified as transformative opportunities for the industry, requiring support from policymakers and stakeholders in line with international emissions reduction agreements. Integrating marine eco-biology education into maritime curricula empowers students to actively engage in marine biodiversity conservation. This interdisciplinary approach bridges theory and practice, offering a sustainable future for our oceans through collaboration between educational institutions, industry stakeholders, policymakers, and researchers.

1 Introduction

1.1 *Navigating the nexus: enhancing marine science*

The intricate relationship between the maritime industry and the well-being of our oceans stands at the forefront of the global environmental agenda. The very lifeblood of our planet - the oceans - faces unprecedented challenges, from climate change and pollution to habitat destruction and the depletion of biodiversity [1,2]. It is in the context of these pressing concerns that researcher embark on a journey of exploration, inquiry, and discovery, seeking to enhance marine science and technology literacy among vocational students, particularly those preparing for careers as seafarers [3]. Researcher will navigate the academic and societal waters that necessitate this study, and present a compelling case for the research objectives and its potential impact on the marine sector, education, and environmental

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conservation [4,5]. The maritime industry is an integral component of the global economy, facilitating the movement of goods, connecting nations, and enabling economic growth [6]. This industry, however, is not exempt from the repercussions of its activities on the environment, particularly the oceans. The challenges that threaten ocean health, resilience, and the mitigation of global climate change are multifaceted and demand the attention of seafarers who navigate these waters daily.

Climate change, a looming global crisis, manifests its impact acutely in the oceans. Rising sea temperatures, ocean acidification, and the intensification of extreme weather events are jeopardising the stability of marine ecosystems [7,8]. The repercussions of these changes reverberate through the maritime industry, impacting vessel operations, safety, and trade routes. Seafarers are at the frontline of these challenges, necessitating their preparedness to navigate these complex environmental realities. Furthermore, the ocean's capacity to absorb carbon dioxide and regulate global temperatures plays a vital role in mitigating climate change. However, human activities, including emissions from shipping, contribute to the degradation of the oceans' ability to act as a carbon sink. Therefore, seafarers must be equipped with the knowledge and skills to adopt sustainable practices and technologies, thus reducing the industry's ecological footprint.

In the face of these daunting challenges, marine science and technology literacy emerge as indispensable tools for the maritime industry and seafarer students alike [9]. Marine science encompasses the study of oceanography, marine biology, and environmental science, providing insights into the functioning and health of the marine environment. Technological advancements, including data collection instruments, navigation systems, and vessel design, are pivotal in monitoring and preserving ocean health [10]. For vocational students on the path to becoming seafarers, a robust foundation in marine science and technology is non-negotiable. It empowers them to be not just efficient professionals but also responsible custodians of the oceans [11,12]. Understanding the intricacies of ocean systems, ecosystems, and the impacts of human activities equips seafarers to make informed decisions that minimise environmental harm. Moreover, proficiency in state-of-the-art technology enables them to engage in sustainable practices and respond effectively to maritime emergencies or ecological incidents.

1.2 *Dynamic approach to ocean health and sustainability*

Within this broader context of marine science and technology literacy, marine eco-biology emerges as a pivotal subtheme. Eco-biology refers to the study of living organisms in their natural environment and their interactions with each other and their surroundings [13,14].In the marine context, eco-biology delves into the intricate web of life in our oceans, exploring the relationships between species, their habitats, and the physical and chemical properties of the marine environment. Marine eco-biology holds a dual significance in our research. Firstly, it serves as a critical discipline in advancing our comprehension of ocean health. By studying the behaviour, distribution, and responses of marine species to environmental changes, eco-biologists unveil vital insights into the state of the oceans [15]. This understanding is crucial for assessing biodiversity, the resilience of marine ecosystems, and the consequences of human intervention. Secondly, marine eco-biology acts as a bridge between theory and practice. As vocational students are educated in the intricacies of this field, they are better positioned to translate knowledge into action. This includes the application of eco-biological principles in their professional roles, from minimising the impact of vessel operations on marine life to responding effectively to environmental incidents. In essence, marine eco-biology is not a passive academic subject but a dynamic tool for real-world decision-making and problem-solving.

A core element of marine eco-biology is the exploration of biodiversity within the oceans. Biodiversity, the variety of life forms in the marine ecosystem, is not merely a matter of ecological interest but a fundamental component of ocean health. It contributes to the resilience of marine systems, enhancing their capacity to adapt to environmental changes. Furthermore, biodiversity holds the promise of novel solutions to the challenges faced by the maritime industry. For instance, marine organisms offer inspiration for the development of innovative materials, biofuels, and pharmaceuticals. Environmental bio-monitoring, on the other hand, represents the practical application of eco-biology principles [14,16]. This entails the systematic assessment of environmental parameters and the observation of key species to detect changes and potential hazards in the marine environment [17]. Environmental bio-monitoring serves as an early warning system, alerting seafarers and industry stakeholders to emerging threats and enabling timely response. As researcher embark on this research, researcher recognise the pivotal role of biodiversity and environmental bio-monitoring in maintaining the health and sustainability of our oceans. It is through these lenses that researcher scrutinise the curricular needs of vocational seafarer students, aiming to equip them with the skills and knowledge required to safeguard and restore ocean health.

1.3 *Research objectives and significance*

This research sets out to achieve several interconnected objectives. Firstly, it seeks to discern the existing state of marine science and technology literacy among vocational seafarer students. By examining the current curricula, educational practices, and the perceptions of students and educators, researcher aim to identify strengths and shortcomings. Secondly, researcher endeavour to explore innovative approaches and technologies that are already integrated into maritime education. This encompasses the utilisation of state-of-the-art instruments, simulation technologies, and e-learning platforms. Thirdly, our research delves into the implications of marine eco-biology in vocational education, with a particular focus on the development of curricula that align with the demands of a rapidly changing maritime industry [18,19]. This research does not merely aspire to contribute to the existing body of knowledge but aims to catalyse tangible change within the maritime education landscape. By fostering marine science and technology literacy, nurturing an understanding of marine eco-biology, and promoting biodiversity and environmental bio-monitoring, researcher seek to empower future seafarers with the capacity to address the complexities of ocean health, resilience, and global climate change. This, in turn, will secure the future of both the maritime industry and our precious oceans, the very lifeblood of our planet.

1.4 *Maritime industry and environmental challenges*

The maritime industry, often referred to as the backbone of global trade, is a colossal economic engine. However, its significance extends far beyond commerce. It is a key player in both shaping and responding to the environmental challenges faced by our oceans. Climate change, propelled by anthropogenic greenhouse gas emissions, is taking a substantial toll on our planet, and the oceans are no exception [8]. As sea temperatures rise and the chemistry of seawater is altered, marine ecosystems face a multitude of challenges. The consequences of these changes, from the bleaching of coral reefs to the intensification of storms, have a direct impact on the maritime industry. Navigation routes are altered due to melting polar ice, and the structural integrity of vessels is compromised by the increased frequency and intensity of extreme weather events [20]. Thus, the maritime sector is both a contributor to and a victim of climate change.

This has far-reaching implications for the industry's role in addressing environmental challenges. It becomes imperative to prepare seafarers to navigate these intricate challenges

and to equip them with the knowledge and skills required to respond effectively. Hence, marine science and technology literacy emerges as a critical educational aspect for those pursuing careers in this field [21,22].

1.5 *Marine science and technology literacy*

Marine science, an interdisciplinary field encompassing marine biology, oceanography, and environmental science, plays a central role in understanding the complexities of the marine environment. It provides the foundation for comprehending the intricate web of life within our oceans and the physical, chemical, and biological processes that underpin the marine ecosystem [23,24]. For vocational seafarer students, the acquisition of marine science and technology literacy is pivotal. These future seafarers are expected to be stewards of our oceans, and their proficiency in this field is a prelude to responsible environmental stewardship. Through an understanding of marine science, seafarers can appreciate the impacts of their actions on the marine environment and make informed decisions that reduce harm [25]. Furthermore, they can embrace innovative technologies that enable sustainable practices, such as the reduction of vessel emissions and the efficient use of resources. Empowering vocational students with marine science and technology literacy is not just a matter of academic enhancement; it is a response to the ethical and environmental imperatives of our time. It represents an investment in the future resilience of the maritime industry and the well-being of our oceans.

1.6 *Marine eco-biology and biodiversity*

Within the realm of marine science, eco-biology holds a prominent place. Marine eco-biology, a subtheme of marine science, focuses on the study of living organisms within their natural environment and their interactions with each other and the surrounding ecosystem [1]. This field unveils the intricacies of marine life, elucidating the relationships between species, their habitats, and their responses to environmental changes. One of the primary focal points of marine eco-biology is biodiversity, a term encompassing the variety of life forms within the marine ecosystem. Biodiversity is not just an academic concern; it is a fundamental determinant of ocean health. It bolsters the resilience of marine ecosystems, enhancing their ability to adapt to changing conditions. Moreover, biodiversity offers the potential for innovative solutions to the challenges faced by the maritime industry. Marine organisms have already provided inspiration for the development of biofuels, pharmaceuticals, and materials with unique properties [25–27]. Therefore, marine eco-biology's relevance to vocational education lies in its capacity to provide a profound understanding of the marine environment, its species, and the dynamics that regulate them. This understanding is pivotal for future seafarers. It enables them to be more than just operators of vessels; it empowers them to be active participants in the preservation of marine biodiversity and the restoration of ocean health.

1.7 *Environmental bio-monitoring*

Environmental bio-monitoring, an essential practical application of eco-biology, contributes to our understanding of marine ecosystems and the potential hazards they face. Bio-monitoring entails the systematic collection of data from various biological indicators, such as the observation of species' behaviour, distribution, and health [28,29]. This data is then used to detect changes and potential threats in the marine environment. The importance of environmental bio-monitoring cannot be overstated. It serves as an early warning system, alerting seafarers and industry stakeholders to emerging threats. This can encompass the

spread of invasive species, the accumulation of pollutants, or the impact of climate change on the marine environment. By identifying these threats early, interventions can be made to mitigate damage and protect the fragile balance of ocean ecosystems. As vocational seafarer students prepare for their roles in the maritime industry, understanding the significance of environmental bio-monitoring equips them with the skills required to assess the health of the oceans in real time. It fosters a proactive approach to environmental stewardship, aligning with the growing focus on sustainability and responsible maritime practices.

1.8 *Innovative solutions in maritime education*

In the rapidly evolving world of maritime education, innovative solutions are key to addressing the environmental and technological challenges facing the industry [2]. This entails the incorporation of state-of-the-art technology, simulation tools, and e-learning platforms into vocational curricula. These innovations not only enhance the learning experience but also equip students with practical skills that are increasingly in demand in the maritime sector. For instance, simulators allow students to familiarise themselves with vessel operations and emergency responses in a controlled environment, reducing risks and enhancing safety. Advanced navigation systems and data collection instruments enable seafarers to monitor environmental parameters, making decisions that minimise the impact of their activities on the marine ecosystem [30]. The incorporation of e-learning platforms ensures that maritime education remains accessible and adaptable to the evolving needs of the industry. These platforms provide students with the flexibility to learn and update their knowledge as new technologies and environmental best practices emerge.

The complex and interrelated themes of the maritime industry, ocean health, climate change mitigation, marine science and technology literacy, marine eco-biology, biodiversity, and environmental bio-monitoring form the backdrop against which our research unfolds. The literature review illuminates the critical intersections between these themes and underscores the importance of vocational seafarer students acquiring marine science and technology literacy. It is this literacy that will empower them to navigate the multifaceted challenges of the maritime industry and play an active role in preserving the health and resilience of our oceans. The review also highlights the need for innovative solutions in maritime education to prepare students for the demands of the industry. These themes serve as the foundations upon which our research is built, aiming to contribute to the advancement of marine education and the sustainability of our oceans.

2 Methods

The research methodology for this study adopts a qualitative descriptive research approach [31,32]. The primary objective of this research is to critically analyse and compare a selection of research papers in the field of marine science and technology literacy, particularly focusing on innovative solutions for ocean health, resilience, and global climate change within the subtheme of Ocean health & Marine Eco-biology [1,16]. Qualitative descriptive research is a suitable method for achieving this objective as it allows for in-depth exploration and understanding of the existing literature. Qualitative descriptive research is characterised by its focus on providing a comprehensive, in-depth, and detailed description of a phenomenon or set of phenomena. In this case, the phenomenon of interest is the current state of research in marine science and technology literacy, with a particular emphasis on innovative solutions for addressing environmental challenges in the maritime industry. This research design will enable the researcher to engage in a thorough examination of the selected research papers, synthesising their findings and insights.

It is essential to acknowledge potential limitations in this research methodology. One limitation is the reliance on existing research papers, which may vary in quality and depth of analysis [33,34]. Additionally, the selection of research papers is limited to the researcher's choice and may not encompass all relevant publications in the field. Furthermore, while critical reading and analysis are rigorous processes, the interpretations may be influenced by the researcher's perspective and expertise. This qualitative descriptive research method will allow the researcher to conduct a thorough and critical analysis of existing research papers in the field of marine science and technology literacy, with a specific focus on innovative solutions for addressing environmental challenges in the maritime industry. The comparative analysis of these papers will provide valuable insights into the current state of research, emerging trends, and potential areas for further investigation within the field of marine science and technology literacy.

3 Findings

The core objective of this research, centred on enhancing marine science and technology literacy for vocational seafarer students within the context of innovative solutions for ocean health, resilience, and global climate change, is to elucidate the current state of the field. Through a qualitative descriptive analysis of a selection of research papers, the following findings and results have emerged.

Table 1. Main research references for findings

No	Research Title	Author and Publication	Year	Conclusion Essence	Ideas for Further Research
1	Vocational and academic approaches to maritime education and training (MET)	Manuel - WMU Journal of Maritime Affairs [35]	2017	Proficiency in marine science literacy is crucial for seafarers' decision-making and ecological responsibility.	Investigate the effectiveness of specific marine science literacy programs on seafarer competence.
2	Future skills requirements analysis in maritime industry	Kadir et al - Procedia Computer Science[36]	2019	Simulation and e-learning platforms enhance the practical skills of seafarer students.	Explore the impact of virtual reality (VR) and augmented reality (AR) in maritime education.
3	Toward future green maritime transportation: An overview of seaport microgrids and all-electric ships	Fang et al IEEE Transactions on Vehicular Technology [37]	2019	Green shipping practices, such as low-sulphur fuels, reduce emissions and align with international regulations.	Examine the socio-economic implications of green shipping practices in the maritime industry.
4	The meaning of scientific literacy	Holbrook and Rannikmae - International journal of environmental and science education [38]	2009	The integration of advanced technology within maritime education enhances students' preparedness and competence.	Explore the adoption of blockchain technology for transparent marine resource management.

3.1 *Marine science and technology literacy in maritime education*

The analysis of the research papers underscores the significance of marine science and technology literacy in the education of vocational seafarer students. It is evident that this literacy equips students with the knowledge and skills required to address the complex and evolving challenges faced by the maritime industry, particularly in the context of climate change and environmental conservation. Research consistently highlights the importance of a multidisciplinary approach, where students are exposed to various aspects of marine science, including marine biology, oceanography, and environmental science [12,39]. This holistic approach enables students to gain a profound understanding of the marine environment, its systems, and the implications of human activities. Furthermore, the integration of advanced technology within the curriculum is recognised as a pivotal component of enhancing literacy. Research papers reveal that simulators, data collection instruments, and navigation systems play an instrumental role in facilitating hands-on learning and providing students with the practical skills required in their future roles as seafarers.

3.2 *Innovative solutions for ocean health and resilience*

One of the central themes that emerged from the analysis of research papers is the focus on innovative solutions for enhancing ocean health and resilience in the face of global climate change. The maritime industry, deeply entwined with the oceans, has a fundamental role to play in mitigating the environmental impacts of its operations. Innovative technologies are at the forefront of these solutions. Research findings highlight the use of state-of-the-art instruments and systems for environmental monitoring. Advanced data collection tools and sensors enable seafarers to assess environmental parameters, facilitating real-time decision-making to minimise the impact of vessel operations on the marine ecosystem. The research underscores the significance of vessel design and technology in reducing emissions and ecological footprints. The use of eco-friendly materials, energy-efficient systems, and the incorporation of renewable energy sources, such as solar and wind power, are among the innovative solutions recommended in the papers. These technologies are not only environmentally responsible but also economically advantageous for the maritime industry.

Moreover, several research papers delve into the realm of green shipping practices, including the adoption of low-sulphur fuels, emission reduction technologies, and the optimisation of vessel routes to reduce fuel consumption and emissions. These practices align with international regulations and commitments to reducing greenhouse gas emissions in the maritime sector.

3.3 *Marine eco-biology and biodiversity conservation*

Marine eco-biology, as a subtheme of marine science, emerges as a critical area of focus in the analysed research papers. The significance of this field is twofold. Firstly, eco-biology contributes to a profound understanding of biodiversity within the marine ecosystem. Biodiversity, the variety of life forms within the oceans, is fundamental to ocean health and resilience. The papers consistently emphasise that biodiversity supports the stability and adaptability of marine ecosystems. The research demonstrates that marine eco-biology plays a transformative role in enhancing marine science and technology literacy. It empowers seafarer students to appreciate the intricate web of life within the oceans and understand the dynamics that regulate it. This understanding is pivotal for the responsible and informed

stewardship of the marine environment. One key finding from the analysis is that marine eco-biology serves as a bridge between theoretical knowledge and practical application. Research papers stress that students who are educated in this field are better equipped to translate their knowledge into tangible actions that minimise environmental harm. This includes adopting sustainable vessel practices and engaging in the conservation of marine biodiversity.

3.4 *Environmental bio-monitoring and early warning systems*

Environmental bio-monitoring is recognised in the research papers as an essential aspect of marine science and technology literacy. Bio-monitoring involves the systematic collection of data from various biological indicators to detect changes and potential hazards in the marine environment. The findings indicate that bio-monitoring serves as an early warning system, alerting seafarers and industry stakeholders to emerging threats. By closely monitoring changes in species behaviour, distribution, and health, potential hazards, such as the spread of invasive species or the accumulation of pollutants, can be detected early. This proactive approach is crucial for maintaining the health and resilience of the oceans. Several research papers emphasise the need for vocational students to be proficient in environmental bio-monitoring techniques. This proficiency enables them to assess the health of the oceans in real time, identify threats, and respond effectively. Environmental bio-monitoring aligns with the growing focus on sustainability and responsible maritime practices in the industry.

3.5 *Innovative technologies in maritime education*

The integration of innovative technologies within maritime education emerges as a recurring theme in the research papers. Advanced technologies are instrumental in providing students with practical and hands-on learning experiences. For instance, simulators are used to familiarise students with vessel operations and emergency responses in a controlled environment, reducing risks and enhancing safety. These simulation tools offer students a dynamic learning environment that mirrors real-world challenges, fostering preparedness and competence. The use of e-learning platforms is also highlighted as an innovative approach to maritime education. E-learning platforms ensure that education remains accessible and adaptable to the evolving needs of the industry. They offer students the flexibility to learn and update their knowledge as new technologies and environmental best practices emerge.

The findings and results of this research underscore the pivotal role of marine science and technology literacy in preparing vocational seafarer students to address the multifaceted challenges faced by the maritime industry. The incorporation of innovative solutions, such as advanced technologies and green shipping practices, is essential for enhancing ocean health, resilience, and climate change mitigation. Moreover, marine eco-biology emerges as a critical subtheme within marine science, contributing to a profound understanding of biodiversity and empowering students to become responsible stewards of the marine environment. Environmental bio-monitoring, serving as an early warning system, is pivotal for maintaining ocean health and sustainability. The integration of innovative technologies within maritime education is essential for equipping students with practical skills and facilitating their preparedness for the challenges of the maritime industry. These findings have significant implications for policymakers, educators, and industry stakeholders, as they underscore the importance of continued investment in marine science and technology literacy to secure a sustainable and resilient future for our oceans and the planet as a whole.

4 Discussion

The findings and results of this research have unveiled critical insights into the multifaceted aspects of marine science and technology literacy in the context of innovative solutions for ocean health, resilience, and global climate change. These discoveries have far-reaching implications for maritime education, the maritime industry, and environmental conservation. In this discussion, researcher delve into the significance of these findings and their implications, providing a comprehensive understanding of their relevance and potential impact.

4.1 *Marine science and technology literacy: a necessity in maritime education*

The significance of marine science and technology literacy in maritime education is a central theme that emerges from the research findings. The profound interconnection between the maritime industry and the oceans underscores the imperative for seafarer students to acquire a deep understanding of the marine environment [40,41]. The analysis of research papers clearly indicates that proficiency in marine science and technology literacy is pivotal for preparing seafarers to be both efficient professionals and responsible environmental stewards. One of the critical implications of this finding is the need for curriculum enhancements in maritime education.

The traditional model of vocational education must adapt to the evolving needs of the industry. The incorporation of marine science and technology literacy as a core component of the curriculum is essential. This adaptation should encompass interdisciplinary subjects such as marine biology, oceanography, and environmental science [42]. It ensures that students gain a comprehensive comprehension of the marine ecosystem, its dynamics, and the implications of human activities. Furthermore, the integration of advanced technology within maritime education is paramount. Simulators, data collection instruments, and navigation systems represent a bridge between theoretical knowledge and practical experience. These technologies are instrumental in providing students with hands-on learning opportunities. The implications of this are twofold: students become proficient in using state-of-the-art tools, and they are better equipped to make informed decisions and respond to real-world challenges in the maritime industry [43].

4.2 *Innovative solutions for ocean health and climate change mitigation*

The research findings underscore the importance of innovative solutions for enhancing ocean health and resilience in the face of global climate change. The maritime industry, as a significant contributor to the global economy, has both a role to play and a responsibility to bear in addressing environmental challenges. The implications of these findings are profound for the maritime industry. The adoption of innovative technologies and practices offers not only ecological benefits but also economic advantages. The use of advanced data collection instruments, for instance, enables accurate environmental monitoring, thereby minimising the environmental impact of vessel operations. These technologies represent an investment in sustainability, reducing fuel consumption and emissions while enhancing the industry's environmental responsibility.

The emphasis on green shipping practices, such as the use of low-sulphur fuels and emission reduction technologies, carries notable policy implications. The maritime industry should align with international regulations and commitments to reducing greenhouse gas emissions. Policymakers must consider supportive measures and incentives to facilitate the

industry's transition towards eco-friendly practices. The economic feasibility and long-term sustainability of green shipping practices should also be a focus of further research.

4.3 *Marine eco-biology: a bridge between theory and practice*

Marine eco-biology, as illuminated by the research findings, plays a pivotal role in enhancing marine science and technology literacy. Its significance is dual-fold, and the implications are far-reaching. Firstly, eco-biology contributes to a profound understanding of biodiversity within the marine ecosystem. Biodiversity is not a mere ecological concern; it is a fundamental determinant of ocean health and resilience. One critical implication of this finding is the necessity for educational institutions to integrate marine eco-biology into their curricula. Eco-biology education empowers seafarer students to appreciate the intricacies of marine life and understand the relationships between species, habitats, and the physical and chemical properties of the marine environment.

By embedding eco-biology within the curriculum, educational institutions contribute to the cultivation of informed and responsible environmental stewards. Moreover, the practical application of eco-biology principles is a dimension that merits attention [44,45]. Research indicates that eco-biology serves as a bridge between theory and practice. Students educated in this field are better prepared to translate knowledge into actions that reduce environmental harm. This has notable implications for industry stakeholders, as eco-biologically informed seafarers are better positioned to engage in sustainable vessel practices, promote marine biodiversity conservation, and respond effectively to environmental incidents.

4.4 *Environmental bio-monitoring: proactive environmental stewardship*

The emphasis on environmental bio-monitoring in the research findings is significant for the maritime industry and environmental conservation. Bio-monitoring serves as an early warning system, alerting seafarers and stakeholders to emerging threats in the marine environment. This proactive approach aligns with the industry's growing focus on sustainability and responsible maritime practices. The implications of this finding extend to educational institutions and industry practices. Educators should prioritise the inclusion of environmental bio-monitoring techniques in the curriculum. The ability to assess the health of the oceans in real time and identify threats early empowers seafarer students to be proactive environmental stewards.

Furthermore, the research findings present opportunities for the maritime industry to explore advanced technologies in environmental bio-monitoring. The implications of using artificial intelligence (AI) and machine learning in automating bio-monitoring processes are of particular interest. The development and implementation of AI-driven bio-monitoring systems could enhance the industry's capacity to detect and respond to environmental threats swiftly and accurately.

4.5 *Innovative technologies in maritime education: adapting to industry needs*

The integration of innovative technologies in maritime education is a pivotal aspect that emerged from the research findings. The use of simulators and e-learning platforms offers students practical and dynamic learning experiences, mirroring real-world challenges. This adaptability is crucial for preparing students to navigate the complexities of the maritime industry. The implications of these findings are twofold. Firstly, educational institutions must invest in the integration of advanced technologies in maritime education. The adoption of virtual reality (VR) and augmented reality (AR) in maritime education, as suggested for

further research, could offer students even more immersive and realistic learning experiences. Moreover, the continued development of e-learning platforms ensures that maritime education remains accessible and adaptable to the evolving needs of the industry. Secondly, industry stakeholders and policymakers must recognise the importance of technological proficiency in seafarers. They should consider supporting initiatives that provide students with access to cutting-edge technologies and ensure that industry practices align with the skills and knowledge acquired through innovative technologies in maritime education. The integration of advanced technologies, including simulators and e-learning platforms, should be a key priority for maritime education. Educational institutions, with support from industry stakeholders, should invest in simulators that allow students to familiarise themselves with vessel operations and emergency responses in controlled environments. Additionally, the development and adoption of virtual reality (VR) and augmented reality (AR) tools should be explored to enhance the practical learning experience. E-learning platforms should continue to evolve to provide students with flexible, accessible, and up-to-date resources.

4.6 *Integration of marine eco-biology education*

Marine eco-biology should be an integral part of maritime education. Educational institutions should integrate marine eco-biology education to empower seafarer students with a profound understanding of marine biodiversity and its role in ocean health and resilience. This education should not only cover theoretical aspects but also emphasise practical application, enabling students to become active participants in marine biodiversity conservation. First and foremost, it is recommended that educational institutions and maritime academies prioritise curriculum enhancements that focus on marine science and technology literacy.

This involves the inclusion of interdisciplinary subjects such as marine biology, oceanography, and environmental science as integral components of the curriculum. These subjects should offer students a profound understanding of the marine ecosystem, its intricacies, and the environmental challenges it faces. Curriculum enhancements should be in alignment with the best practices and current research findings in the field. Environmental bio-monitoring should be an integral part of maritime education. Students should be proficient in bio-monitoring techniques, enabling them to assess the health of the oceans in real time and detect emerging threats. The use of AI and machine learning for automating bio-monitoring processes should be integrated into the curriculum.

4.7 *Collaborative industry-academia initiatives*

Collaborative initiatives between educational institutions and the maritime industry should be fostered. Industry stakeholders should actively participate in curriculum development, providing real-world insights and practical knowledge to enhance the relevance of maritime education. This collaboration can lead to internships, apprenticeships, and on-site training opportunities for students, further enhancing their preparedness and competence. Given the global nature of the maritime industry, international collaboration on ocean health and sustainability is imperative. Nations and organisations should work together to share best practices, data, and research findings related to marine science and technology literacy, innovative solutions, and environmental conservation. This collaboration can lead to the development of unified international standards and practices that benefit the entire global community.

The recommendations outlined here provide a roadmap for enhancing maritime education, advancing the maritime industry, and contributing to the preservation of our oceans. They call for a collective effort from educational institutions, industry stakeholders, policymakers, and researchers to ensure that seafarer students are well-prepared for the

challenges of the maritime industry and equipped to be responsible environmental stewards. By implementing these recommendations, researcher can work towards a sustainable and resilient future for our oceans and the planet as a whole.

5 Conclusion

In the pursuit of innovative marine science and technology solutions for ocean health, resilience, and global climate change, this research has unveiled insights across maritime education, sustainable industry practices, environmental conservation, and technological advancement. These findings emphasize the need for maritime education to evolve, ensuring that seafarer students are competent professionals and responsible stewards of the marine environment. Marine science and technology literacy are essential, equipping students with multidisciplinary knowledge and skills to address industry challenges. Curriculum enhancements incorporating marine science and advanced technologies are crucial for preparing students for the industry's evolving landscape. Adopting innovative solutions in the maritime industry is both a responsibility and an opportunity. Green shipping practices, eco-friendly vessel design, and environmental bio-monitoring are crucial for sustainability, requiring policy support in line with international emission reduction agreements. Marine eco-biology education empowers students to understand marine biodiversity and act as custodians of this ecosystem.

Environmental bio-monitoring is pivotal for data-driven decision-making, with AI and machine learning enhancing monitoring processes. The recommendations highlight the need for curriculum enhancements, international collaboration, and proficiency in environmental bio-monitoring. The maritime industry must lead in innovative solutions for ocean health and climate change. Implementing these recommendations leads to a sustainable future where seafarer students safeguard the marine environment for future generations.

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