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Integrating Sustainability, Green Technologies, and Industry Collaboration in Enhancing Maritime Education for Future Seafarers

M.B. Simanjuntak, T. Cahyadi, W. Winarno, L. Barasa & M. Simanjuntak
Sekolah Tinggi Ilmu Pelayaran, Jakarta, Indonesia

ABSTRACT: This research explores the enhancement of maritime education with a focus on integrating sustainability, green technologies, and stronger industry collaboration to better prepare future seafarers. The analysis was motivated by the growing need to adapt maritime training to meet the challenges of an evolving global maritime industry, which increasingly demands expertise in environmental sustainability and emerging maritime technologies. While previous research has acknowledged the importance of these areas, there has been limited focus on how effectively they are incorporated into maritime curricula. The research aimed to answer key questions regarding the integration of green technologies and sustainability into maritime education and the role of industry partnerships in bridging the gap between education and practical application. Using qualitative interviews with maritime professionals, lecturers, and graduates, this study applied a systematic literature to analyze the findings and identify trends in current practices. Results indicated that while there are efforts to integrate sustainability, further enhancement is needed in curriculum development, with a stronger emphasis on interdisciplinary learning and regulatory knowledge. The research concluded that improving collaborations between industry and academia, alongside updating curricula to focus on sustainability and green technologies, is crucial for preparing future seafarers. These findings provide a roadmap for maritime institutions to adapt to the changing needs of the industry and contribute to the development of a more sustainable maritime workforce.

1 INTRODUCTION

The maritime industry, particularly in the domain of maritime transportation, is undergoing a profound transformation driven by environmental challenges, technological advancements, and an increasing demand for sustainability [1], [2]. As we face the pressing need to adapt to environmental regulations, green shipping technologies, and a commitment to reduce the industry's carbon footprint, the focus on preparing the next generation of maritime professionals becomes more critical than ever. This growing urgency for maritime education and its alignment with sustainability goals, green technologies, and evolving industry needs underpins the central theme of this research: enhancing, improving, and developing maritime education for future seafarers, with a particular focus on engineering technology and environmental sustainability. As maritime professionals, lecturers, and researchers continue to explore how to prepare future seafarers to meet the challenges of a rapidly changing maritime world, this study aims to offer new insights that can contribute to shaping the next generation of maritime professionals equipped with the skills, knowledge, and competencies to thrive in a green and sustainable maritime environment [3], [4].

The background to this study is rooted in the increasing global recognition of the maritime sector's

responsibility to reduce its environmental impact. With rising concerns over climate change, marine pollution, and the depletion of natural resources, the maritime industry is striving to meet international standards for sustainability. In particular, the emphasis is on green shipping technologies, environmental chemistry, and sustainable engineering practices that minimize the ecological footprint of maritime activities. However, the transition toward sustainability in the maritime sector is not only dependent on technological innovations but also requires a shift in educational frameworks and approaches that will train future seafarers to operate effectively in this new context. As the maritime sector continues to expand and evolve, there is a critical need to rethink and enhance seafarer education. Seafarers play a vital role in ensuring the implementation of green technologies and the successful operation of sustainable maritime practices [5], [6]. Therefore, the question arises: How can maritime education be transformed to better equip future seafarers with the necessary skills, competencies, and knowledge to navigate and shape a sustainable maritime industry? This research seeks to answer this question by exploring the perspectives of maritime professionals, educators, and graduates, and identifying the specific areas where educational and technological advancements can be made.

The research problem focuses on the need to develop a comprehensive educational framework that incorporates the most recent technological advancements, sustainability practices, and industry requirements into seafarer training programs. While there has been significant progress in maritime education, it is clear that traditional educational models are no longer sufficient to meet the demands of an industry that is rapidly evolving to incorporate green technologies and sustainable practices. As the maritime industry increasingly integrates environmental considerations into its operations, the educational needs of future seafarers must also evolve. This research aims to investigate the gaps in the current maritime education system and identify the key elements that can be enhanced or developed to ensure that seafarers are fully prepared to meet the challenges of the future. In particular, it examines how maritime education programs can better integrate environmental chemistry, green chemistry, and sustainable engineering practices into the curriculum. The study also explores how lecturers and trainers can be better equipped to teach these concepts, and how industry professionals can help shape the curriculum to ensure that it is both relevant and forward-thinking.

The objectives of this research are multi-dimensional. First, it aims to analyze the current state of maritime education and technology, with a particular focus on how engineering, environmental, and sustainability principles are currently being integrated into seafarer training programs. Second, the research seeks to explore the perspectives of maritime professionals, lecturers, and graduates to understand the gaps in existing curricula and identify specific areas where improvements can be made. Third, the study investigates how the inclusion of new technologies, sustainable practices, and interdisciplinary knowledge (such as environmental chemistry and green shipping) can enhance the competencies of future seafarers. Finally, the research aims to propose recommendations for enhancing, improving, and developing maritime education programs to better align them with the industry's future needs, with a particular focus on the growing emphasis on sustainability.

The rationale for this study lies in the urgent need to ensure that maritime education is not only aligned with current technological developments but is also forward-thinking in preparing future professionals for a world in which sustainability is central. As green shipping technologies continue to emerge and environmental regulations become more stringent, seafarers must be educated to not only understand these innovations but also to effectively implement them in their daily work. This research is motivated by the desire to create an educational model that not only addresses the technical needs of the maritime sector but also emphasizes the environmental and sustainability considerations that are crucial for the future of the industry. The motivation for this research is driven by the belief that maritime education should evolve in tandem with technological advancements and environmental imperatives, ensuring that the next generation of seafarers is well-equipped to lead the industry toward a more sustainable and technologically advanced future.

In terms of methodology, this study employs a qualitative research design, with a focus on the experiences and perspectives of key stakeholders in maritime education and the maritime industry. Data collection is based on interviews with maritime professionals, educators, and graduates, whose insights provide valuable information on the current state of maritime education and the specific areas that need enhancement. Ten participants—three maritime professionals, four lecturers, and three graduates—are selected for their expertise and experience in maritime engineering, environmental science, and green shipping technologies. Through in-depth interviews and qualitative analysis, this research explores their views on the integration of sustainability and engineering technology into maritime education and training. By utilizing qualitative analysis, this study aims to uncover rich, nuanced insights into the challenges and opportunities that exist in transforming maritime education to meet the needs of the future.

The results of this research are expected to contribute significantly to the field of maritime education, engineering technology, and sustainability. By drawing on the perspectives of experienced professionals and educators, the study will offer a comprehensive understanding of the challenges faced by maritime education programs and provide actionable recommendations for how these programs can be enhanced. This research also has the potential to influence the development of future maritime training curricula, ensuring that they are more responsive to the changing needs of the industry. In doing so, the study will contribute to the global effort to create a more sustainable and technologically advanced maritime industry, equipped with professionals who are prepared to face the challenges of the future.

This research seeks to fill a critical gap in the understanding of how maritime education can evolve to meet the challenges of a green and technologically advanced maritime industry. The study's focus on sustainability, green shipping, and engineering

technology highlights the need for a holistic approach to seafarer education—one that prepares future professionals not only with the technical knowledge needed to operate in the maritime industry but also with the competencies required to drive sustainability and technological innovation. This research is essential for shaping the future of maritime education and ensuring that the next generation of seafarers is equipped to lead the industry toward a more sustainable and technologically advanced future. Through qualitative analysis and the insights provided by industry professionals, educators, and graduates, this study aims to make a meaningful contribution to the ongoing transformation of maritime education and its alignment with the future needs of the maritime industry.

2 METHODS

The research methodology for this study is based on a qualitative approach, which seeks to explore the perspectives of maritime professionals, lecturers, and graduates on the enhancement of maritime education with a focus on sustainability, green technologies, and engineering advancements. The methodology is designed to gather in-depth insights into how current educational frameworks can be improved to meet the challenges and demands of the maritime industry, particularly in terms of sustainability and engineering technology. To achieve this, the research employs a purposive sampling strategy, where experts in the field are selected based on specific criteria to ensure a diverse and representative sample. The ten participants in this study include three maritime professionals with backgrounds in marine engineering, port and shipping industries, and maritime company management. These professionals have hands-on experience in the application of green shipping technologies, sustainable practices, and engineering innovations within the maritime sector. Additionally, four lecturers with expertise in maritime education and environmental sciences, as well as three graduates who have completed studies in maritime engineering and technology, are chosen to provide varied perspectives on the current state of maritime education and the industry's future needs.

The selection of these experts is guided by their extensive experience and knowledge in their respective fields. The professionals and educators have a proven track record in maritime education and sustainable maritime practices, ensuring that their input is both relevant and valuable to the research. The graduates provide a critical perspective on how well their educational experiences have prepared them for the challenges they face in the maritime sector, especially in relation to the integration of green technologies and sustainability practices. In-depth interviews serve as the primary data collection method for this study. The interviews are conducted using open-ended questions to encourage participants to provide detailed and rich responses [7], [8]. These questions are framed broadly to allow the participants to express their thoughts freely without leading them toward specific answers. This approach ensures that the data gathered reflects the genuine experiences, insights, and opinions of the participants, which is crucial for understanding the nuances of their perspectives on maritime education and its role in shaping future seafarers. Follow-up questions are used to probe deeper into the participants' responses and to clarify any ambiguities, allowing for a more comprehensive understanding of their views.

Active listening is a critical component of the interview process. The researcher pays close attention not only to the verbal responses but also to non-verbal cues that may reveal additional insights. This attentiveness is essential in building rapport with the participants, ensuring that they feel comfortable sharing their honest opinions. Creating a trusting environment is particularly important when discussing sensitive topics such as educational deficiencies or challenges within the maritime sector. By establishing a respectful and open atmosphere, participants are more likely to engage fully and provide thoughtful responses. After the interviews are completed, the data undergoes a rigorous analysis process. The first step in the analysis is transcription, where the audio recordings of the interviews are transcribed verbatim to ensure that every detail of the conversation is captured accurately. Once transcribed, the data is analyzed using a coding approach that identifies key themes, concepts, and patterns within the responses. The coding process begins with open coding, where initial codes are assigned to significant portions of the data. These codes are then refined through axial coding, which involves organizing and categorizing the data into broader themes and subthemes. Selective coding follows, where the core categories and their relationships are identified, helping to form the central findings of the research.

Throughout the analysis process, memo-writing is employed to document insights, reflections, and interpretations of the data. This allows the researcher to track the evolution of their thinking and to record any emerging ideas or patterns that may require further exploration. Additionally, triangulation is used to enhance the credibility and validity of the findings. Triangulation involves cross-referencing the interview data with other relevant sources, such as existing literature on maritime education and sustainability practices, to ensure that the results are grounded in a broader context. This process helps to confirm the accuracy of the findings and ensures that the conclusions drawn are well-supported by multiple sources of evidence. To ensure the rigor and trustworthiness of the research, several strategies are employed. Member checking is used to validate the findings by sharing preliminary results with the participants to confirm that their views have been accurately represented. This feedback loop helps to refine the analysis and ensure that the interpretations align with the participants' perspectives. Peer review is another key strategy, where other researchers or experts in the field review the analysis to provide constructive feedback and identify any potential biases or gaps in the findings. Thick description is also a crucial element of the research, as it provides detailed accounts of the context and the data, allowing readers to critically evaluate the findings and understand the complexities of the research.

Ethical considerations are a central aspect of this study. Informed consent is obtained from all participants before the interviews are conducted,

ensuring that they are fully aware of the purpose of the study and their role in it. The confidentiality of the participants is maintained throughout the research process, with all personal information and responses kept anonymous. Respectful treatment of the participants is prioritized, ensuring that they are treated professionally and with courtesy at all stages of the research. These ethical considerations are essential in fostering a sense of trust and ensuring the integrity of the research process. The research method is designed to provide a comprehensive and in-depth understanding of the perspectives of maritime professionals, educators, and graduates on the enhancement of maritime education in relation to sustainability, green technologies, and engineering advancements. Through careful selection of participants, rigorous data collection and analysis techniques, and a commitment to ethical practices, the research aims to produce valuable insights that can contribute to the development of future maritime education programs. The findings will inform the ongoing efforts to improve seafarer training and ensure that maritime professionals are equipped to meet the evolving challenges of the industry.

3 LITERATURE REVIEW AND DEVELOPMENT OF HYPOTHESIS

The maritime industry stands at a critical juncture where the need for innovation in education and sustainable practices has never been more pressing [3], [9], [10]. The exploration of sustainability, green technologies, and engineering advancements within maritime education is essential not only for the current generation of seafarers but also for the next. This research is driven by the need to enhance the competencies of future maritime professionals, equipping them with the knowledge and skills necessary to navigate the complexities of the green shipping transition. As the demand for sustainable maritime practices grows, the urgency to align maritime education with these trends becomes evident. This section provides a systematic review of existing literature in the context of maritime education, sustainability, and engineering technology, with a focus on the evolving needs of maritime professionals. Additionally, it proposes hypotheses grounded in this literature, offering insights into the potential pathways for enhancing maritime education and practice.

The literature surrounding maritime education reveals a growing concern with the industry's capacity to prepare future seafarers for the challenges posed by environmental and technological advancements [11]. Traditional maritime education has often been criticized for its insufficient integration of sustainability principles and green technologies. While the primary objective of maritime education has historically been the development of technical competencies in navigation, engineering, and maritime law, there is a shift toward incorporating sustainability as a core component of the curriculum. This shift reflects the increasing emphasis on reducing the environmental impact of maritime operations, such as minimizing greenhouse gas emissions, reducing marine pollution, and adopting sustainable shipping practices. As a result, maritime education programs are beginning to emphasize the development of both technical skills and the ability to engage with broader environmental concerns.

The role of green technologies in maritime operations is another key theme in the literature. Green shipping technologies encompass a wide range of innovations, including alternative fuels, energy-efficient engines, emission-reducing technologies, and waste management systems [12]. These technologies have the potential to significantly reduce the maritime industry's carbon footprint, but their effective implementation depends on the education and training of seafarers. Maritime professionals must be equipped with a comprehensive understanding of these technologies to ensure their successful deployment [13]–[15]. This includes knowledge of alternative fuels such as LNG and biofuels, energy-efficient ship designs, and the operation of emission-control systems. However, the successful integration of these technologies into the industry relies heavily on the educational institutions that train future seafarers. Therefore, one critical area of exploration in the literature is how maritime educational frameworks can be adapted to include training in green technologies, ensuring that seafarers are equipped with the necessary expertise to drive sustainability within the maritime industry.

The theoretical underpinnings of sustainability in maritime education are rooted in systems theory and the concept of sustainable development. Systems theory emphasizes the interconnectedness of different components within a system and the need for a holistic approach to problem-solving. In the context of maritime education, this theory suggests that sustainable practices must be integrated across all aspects of the curriculum, from engineering design to operational management [9], [16], [17]. It also posits that sustainability is not a standalone issue but must be embedded within the broader context of maritime education, including the cultural, legal, and economic factors that shape maritime operations. The systems theory perspective advocates for a more integrated approach to teaching sustainability, one that bridges the gap between technical knowledge, environmental awareness, and management practices.

Another theoretical framework relevant to this research is competency-based education, which emphasizes the development of specific skills and competencies that align with industry needs. In maritime education, competency-based frameworks ensure that students acquire the practical skills necessary for effective performance in their professional roles. These frameworks focus on measurable outcomes, such as the ability to operate advanced maritime technologies, implement sustainable practices, and navigate the legal and regulatory complexities associated with the maritime industry [18], [19]. By incorporating sustainability and green technologies into competency-based frameworks, maritime educational programs can better align with the evolving needs of the industry, ensuring that future seafarers are not only technically proficient but also capable of implementing sustainable practices.

In light of these theoretical perspectives, this research seeks to develop a set of hypotheses that will

guide the investigation of how maritime education can be enhanced to meet the demands of sustainability and technological advancements [20], [21]. The first hypothesis centers on the idea that the integration of green technologies into maritime education will significantly improve the readiness of future seafarers to engage with sustainability initiatives in the maritime industry. This hypothesis is based on the assumption that seafarers equipped with knowledge of green technologies will be better positioned to operate sustainable shipping practices, thus contributing to the reduction of the industry's environmental footprint. The hypothesis further posits that a curriculum that includes green technologies will foster a more comprehensive understanding of sustainability, enabling students to make informed decisions regarding the implementation of these technologies in real-world maritime operations.

The second hypothesis focuses on the role of interdisciplinary learning in enhancing maritime education. This hypothesis proposes that incorporating interdisciplinary approaches, such as environmental chemistry, green chemistry, and biochemistry, into maritime curricula will enhance the environmental awareness and technical capabilities of future seafarers. By bridging the gap between engineering, environmental sciences, and maritime practices, students will develop a more holistic understanding of sustainability [11], [22]. The hypothesis suggests that such an approach will not only improve the technical competence of seafarers but also foster a deeper commitment to sustainability, as students will be better equipped to understand the environmental impact of their decisions and actions.

A third hypothesis is related to the role of industry professionals and educators in shaping the future of maritime education. This hypothesis proposes that a collaborative approach between maritime education institutions and industry stakeholders will lead to more effective training programs that align with the needs of the industry. By involving maritime professionals, such as engineers, managers, and environmental experts, in the development and delivery of curricula, educational institutions can ensure that students are exposed to the latest industry trends, technologies, and sustainability practices. This collaboration is expected to improve the relevance and practical applicability of maritime education, ensuring that seafarers are equipped to meet the challenges of a rapidly evolving industry.

The final hypothesis focuses on the importance of adapting maritime education to the changing regulatory landscape. This hypothesis posits that as international regulations surrounding maritime sustainability become more stringent, the integration of regulatory frameworks into maritime curricula will be essential for preparing future seafarers to comply with these standards. By incorporating maritime law, policy, and international conventions into educational programs, future professionals will gain the knowledge necessary to navigate the complex regulatory environment of the maritime industry [23], [24]. This will not only ensure that seafarers are compliant with legal standards but also equip them with the skills needed to advocate for sustainable practices within their organizations.

These hypotheses are grounded in the existing literature and theoretical frameworks, which suggest that the enhancement of maritime education through the integration of green technologies, interdisciplinary learning, industry collaboration, and regulatory knowledge will result in more competent, environmentally aware, and technically proficient seafarers. The findings of this research will provide valuable insights into how maritime education can be transformed to better meet the challenges of sustainability and technological advancement, contributing to the development of a more sustainable and efficient maritime industry.

The systematic literature review and development of hypotheses reveal a clear need for the transformation of maritime education to address the evolving demands of the maritime industry. The integration of green technologies, interdisciplinary learning, industry collaboration, and regulatory knowledge into maritime curricula is crucial for preparing future seafarers to navigate the challenges of sustainability and technological innovation. The hypotheses proposed in this study provide a framework for exploring how these factors can be incorporated into maritime education to enhance the competencies of future professionals. By aligning maritime education with the industry's sustainability goals, this research aims to contribute to the development of a more sustainable and technologically advanced maritime workforce, capable of meeting the challenges of the future.

4 RESEARCH RESULTS AND ANALYSIS

The research aimed at enhancing maritime education and sustainability practices within maritime vocational training was conducted by gathering qualitative data from a select group of ten participants, consisting of three maritime professionals, four maritime lecturers, and three recent graduates from maritime engineering programs. The results from these participants have been evaluated based on several key indicators, and the overall findings demonstrate high effectiveness and efficiency in achieving the research objectives. These indicators assess the integration of green technologies, sustainability education, interdisciplinary learning, and industry collaboration in maritime education programs, with a specific focus on the development of future seafarers.

4.1 *Overview of Indicators and Scoring*

The research utilized four primary indicators to assess the effectiveness and potential of the proposed enhancements to maritime education. Each indicator was scored on a scale from 1 to 10, where 10 represents the highest level of effectiveness and alignment with the research objectives. The overall scores across all indicators indicate a high degree of alignment with the research's aims of enhancing maritime education and preparing seafarers for sustainable practices in the maritime industry.

The four key indicators were:

1. Integration of Green Technologies into Maritime Education: This indicator assessed how effectively

green technologies, such as alternative fuels, energy-efficient engines, and emission-reducing technologies, are incorporated into the curricula of maritime education programs.
2. Development of Interdisciplinary Approaches in Maritime Training: This indicator measured the degree to which interdisciplinary learning, particularly in fields like environmental chemistry, green chemistry, and biochemistry, is integrated into maritime education programs.
3. Collaboration Between Industry Professionals and Educational Institutions: This indicator evaluated the level of collaboration between maritime education institutions and industry professionals, ensuring that curricula align with the needs of the industry and prepare students to address real-world challenges.
4. Incorporation of Regulatory Knowledge and Sustainability Standards: This indicator focused on the inclusion of regulatory frameworks, international conventions, and sustainability standards in maritime education, particularly in regard to environmental compliance and the green shipping transition.

4.2 *Comprehensive Data and Scoring*

The following table presents a breakdown of the scoring for each of the indicators. The scores were derived from qualitative analysis based on the expert opinions and experiences of the ten participants, which included in-depth interviews and discussions on their perspectives regarding the current state of maritime education and its alignment with sustainability and technological advancements.

The overall scores across the four indicators provide a clear picture of the current state of maritime education and its alignment with the research objectives. The research results indicate that the integration of green technologies, interdisciplinary learning, industry collaboration, and regulatory knowledge are all significant areas of focus in contemporary maritime education. The overall score across all indicators averaged 9 out of 10, reflecting a high degree of effectiveness and alignment with the research's goals.

1. Green Technologies: The integration of green technologies into maritime education has been highly effective, with professionals and graduates alike demonstrating a strong understanding of these technologies and their applications in the maritime industry. However, lecturers noted that while green technologies are increasingly included in curricula, some institutions are still in the process of fully integrating them into their teaching methods.
2. Interdisciplinary Approaches: Interdisciplinary learning has been recognized as a crucial component of maritime education, particularly in fostering environmental and chemical literacy. While there is recognition of the need for this type of learning, some challenges remain in integrating these subjects fully within the existing curricula. Both lecturers and graduates acknowledged the value of interdisciplinary learning, but implementation is still evolving in many maritime institutions.

Table.

Indicator	Participant Group	Score (1-10)	Explanation of Score
1. Integration of Green Technologies into Maritime Education	Maritime Professionals	9	High level of integration, with a strong emphasis on practical applications of green technologies in the maritime industry.
	Lecturers	8	Curriculum development includes green technologies, but implementation is still evolving in some institutions.
	Graduates	9	Graduates have received exposure to green technologies and understand their importance in maritime operations.
2. Development of Interdisciplinary Approaches in Maritime Training	Maritime Professionals	9	Strong recognition of the need for interdisciplinary knowledge, particularly in environmental and chemical sciences.
	Lecturers	8	Interdisciplinary approaches are being implemented but face challenges in integration due to traditional curriculum structures.
	Graduates	8	Graduates recognize the value of interdisciplinary learning, though some felt it was not sufficiently emphasized during their education.
3. Collaboration Between Industry Professionals and Educational Institutions	Maritime Professionals	10	Strong collaboration exists, with professionals actively involved in curriculum development and delivery.
	Lecturers	9	Many lecturers collaborate with industry professionals, though more systematic and structured collaborations are needed.
	Graduates	8	Some graduates experienced limited exposure to industry practices during their education, though this is improving.
4. Incorporation of Regulatory Knowledge and Sustainability Standards	Maritime Professionals	9	Professionals are highly aware of international regulations and sustainability standards, which are integrated into industry practices.
	Lecturers	8	Maritime education institutions are gradually incorporating sustainability standards and international regulations into their curricula.
	Graduates	9	Graduates are well-versed in sustainability standards and international regulations, preparing them for regulatory compliance in the industry.

3. Industry Collaboration: Collaboration between industry professionals and educational institutions emerged as one of the strongest areas in the research. Maritime professionals, particularly those with practical experience in port and shipping industries, highlighted the importance of close collaboration with educational institutions. This

ensures that curricula are aligned with industry needs and that students receive the necessary exposure to real-world challenges and practices. However, lecturers indicated that while collaborations exist, there is room for improvement in structuring these partnerships more systematically.

4. Regulatory Knowledge: The incorporation of sustainability standards and international regulations into maritime education has been well-received by both professionals and graduates. This is critical as the maritime industry faces increasing regulatory pressures related to environmental sustainability. Graduates have demonstrated a strong understanding of these regulations, which indicates that educational institutions are making progress in embedding this knowledge into their curricula.

4.3 *Analysis and Interpretation*

The results of this research reveal that maritime education programs are on the right track toward preparing future seafarers for the challenges of sustainability and technological innovation in the maritime industry. The high scores across all four indicators demonstrate that there is a clear and growing recognition of the importance of integrating sustainability and green technologies into maritime curricula. However, the results also highlight areas where further improvement is needed, particularly in terms of fully integrating interdisciplinary approaches and ensuring consistent industry collaboration. The integration of green technologies is critical to the future of maritime operations, and the results show that this is an area where both professionals and graduates have strong knowledge. This indicates that educational institutions are doing well in preparing students to engage with the green shipping transition. However, as maritime technology continues to evolve, there is a need for continuous updates to curricula to ensure that students are exposed to the latest technological advancements.

Interdisciplinary learning is another area that shows promise but also reveals challenges in full implementation. The importance of understanding the environmental, chemical, and biotechnological aspects of maritime sustainability is recognized, but the integration of these subjects into existing curricula remains a work in progress. For maritime education to fully embrace sustainability, it will be necessary to develop more structured approaches to incorporating these disciplines into the core curriculum, ensuring that future seafarers are equipped with the broad knowledge needed to address the multifaceted challenges of maritime sustainability. Collaboration between industry professionals and educational institutions is one of the most promising aspects of the research. The results indicate that this collaboration has the potential to significantly improve the relevance and practical application of maritime education. By involving professionals in the development and delivery of curricula, educational institutions can ensure that students are well-prepared for the demands of the industry. The strong relationship between industry and education is critical for ensuring that maritime professionals are not only technically proficient but also able to apply their knowledge to real-world situations.

The incorporation of regulatory knowledge into maritime curricula is essential for ensuring that future seafarers are well-versed in the legal frameworks that govern the maritime industry. The results show that students are being equipped with a strong understanding of sustainability standards and international regulations, which will be critical for their success in the industry. The research results demonstrate a high level of effectiveness and efficiency in enhancing maritime education to meet the demands of sustainability and technological advancement. The integration of green technologies, interdisciplinary learning, industry collaboration, and regulatory knowledge are all critical components of maritime education that will prepare future seafarers for the challenges of the green shipping transition. The findings suggest that while significant progress has been made, there is still room for improvement, particularly in terms of fully integrating interdisciplinary approaches and ensuring consistent industry collaboration. Future research should focus on further exploring these areas and developing strategies for enhancing the effectiveness of maritime education in preparing seafarers for a sustainable and technologically advanced future.

5 DISCUSSION OF THE RESEARCH

This research aimed to enhance the education of future seafarers by focusing on key areas such as the integration of green technologies, interdisciplinary learning, industry collaboration, and regulatory knowledge within maritime education. The research findings are based on qualitative data collected from interviews with three maritime professionals, four maritime lecturers, and three graduates from maritime engineering programs. These findings provide valuable insights into the current state of maritime education and highlight areas for improvement. This discussion will interpret the results, compare them with the existing literature, and explore the practical implications of the findings for future maritime education and research.

5.1 *Connecting Qualitative Results to the Research Questions*

The primary research questions revolved around the effectiveness of integrating sustainability, green technologies, and interdisciplinary approaches into maritime education. The findings strongly suggest that the current state of maritime education is moving in the right direction, but challenges remain in fully realizing the potential of these areas. The research questions sought to explore the extent to which green technologies and sustainability principles are embedded in maritime training, how interdisciplinary learning is integrated into curricula, and the level of collaboration between industry professionals and educational institutions.

The findings revealed a high level of alignment between the research questions and the responses from the interviewees. The integration of green technologies

into maritime education received positive feedback, with both professionals and graduates acknowledging the importance of sustainability in the maritime industry [25], [26]. The results support the notion that maritime education has begun incorporating green technologies, although the extent of this integration varies across institutions. Similarly, the development of interdisciplinary approaches in maritime training, particularly in environmental chemistry and biochemistry, was recognized as valuable but still developing. Industry collaboration emerged as a strong point, with a significant number of industry professionals actively involved in shaping maritime curricula, although greater formalization and consistency in these collaborations are necessary [3], [27]. Finally, the incorporation of regulatory knowledge and sustainability standards was identified as a crucial aspect of maritime education, with a clear understanding of international regulations among graduates.

Overall, the research findings provide a comprehensive response to the research questions, demonstrating that while there has been progress in integrating sustainability and technological advancements into maritime education, there is still work to be done. These results suggest that maritime education must continue to evolve to meet the demands of a rapidly changing industry, particularly in the areas of interdisciplinary learning and industry collaboration.

5.2 *Comparing Qualitative Findings to the Literature Review*

When comparing the qualitative findings with the literature reviewed in the earlier stages of this research, it is evident that the results align with many existing studies on the importance of sustainability in maritime education. Previous research has highlighted the growing emphasis on green technologies and environmental sustainability in the maritime sector, and the findings from this study support these claims. Green technologies, such as alternative fuels and energy-efficient engines, are increasingly being incorporated into maritime curricula, as reflected in the high scores given by the participants. This is consistent with the literature, which stresses the need for maritime education to prepare students for the green transition in the industry.

However, there are some differences between the findings of this research and the existing literature, particularly regarding the integration of interdisciplinary learning into maritime curricula. While previous studies have emphasized the importance of interdisciplinary approaches in maritime education, the findings from this study suggest that the full integration of subjects like environmental chemistry and biochemistry is still a work in progress [28]–[30]. This discrepancy could be attributed to the fact that many maritime institutions continue to prioritize traditional technical training, which may leave less room for the integration of interdisciplinary subjects. The slow pace of integrating these subjects could also be related to institutional inertia or a lack of resources to develop comprehensive interdisciplinary curricula.

The collaboration between industry professionals and educational institutions, another key area of focus in the literature, was also well-represented in the findings. The literature highlights the importance of strong industry-academia partnerships to ensure that maritime education remains relevant and responsive to industry needs [31], [32]. The findings from this study support this view, with participants acknowledging the value of industry involvement in shaping curricula. However, the research also found that while industry collaboration exists, it is not always systematically structured, and more formalized partnerships would enhance the overall effectiveness of maritime education. This gap between the existing literature and the findings may reflect the variability in industry-academia collaborations across different regions and institutions.

The incorporation of regulatory knowledge and sustainability standards, as discussed in the literature, was also reflected in the findings. The literature has long emphasized the need for maritime education to address international regulations and environmental compliance, particularly in light of growing concerns about climate change and environmental degradation [33]. The results of this research demonstrate that maritime institutions are increasingly focusing on these areas, with graduates showing a strong understanding of sustainability standards and international regulations. This is consistent with the literature, which underscores the importance of preparing seafarers to navigate complex regulatory environments.

5.3 *Addressing Gaps and Limitations in Previous Studies*

One of the key contributions of this research is its ability to address gaps identified in previous studies. For instance, while much of the literature focuses on the theoretical integration of green technologies and sustainability principles into maritime education, this research provides practical insights into how these areas are being implemented in real-world settings [34], [35]. The findings reveal that green technologies are being incorporated into curricula, but the level of integration varies across institutions. This highlights the need for further research into the specific barriers that prevent full integration and how institutions can overcome these challenges.

Another gap addressed by this research is the examination of the role of interdisciplinary learning in maritime education. While the literature has discussed the importance of interdisciplinary approaches, few studies have explored how these approaches are being implemented in maritime training. This research provides a more detailed understanding of the challenges and opportunities involved in integrating interdisciplinary subjects like environmental chemistry and biochemistry into maritime curricula. The findings suggest that while interdisciplinary learning is valued, its full potential has not yet been realized in many institutions. This provides a basis for future research to explore how interdisciplinary learning can be more effectively integrated into maritime education [36].

Finally, the research also fills a gap in understanding the practical challenges of industry collaboration in maritime education. While the

literature emphasizes the importance of partnerships between industry and academia, this research reveals that while such collaborations are occurring, they are often informal and lack the structure necessary for long-term impact. This finding highlights the need for further research into how industry-academia partnerships can be formalized and made more effective in enhancing the quality and relevance of maritime education.

5.4 *Strengths of the Research*

One of the major strengths of this research is its qualitative approach, which allowed for a deep exploration of the perspectives of key stakeholders in maritime education. By interviewing maritime professionals, lecturers, and graduates, the research provided valuable insights into the real-world challenges and opportunities associated with enhancing maritime education. The qualitative data collected through in-depth interviews enabled the researchers to capture a wide range of perspectives, providing a comprehensive view of the current state of maritime education.

Additionally, the research effectively used a combination of theoretical literature and empirical data to address the research questions. The literature review provided a solid foundation for understanding the key areas of focus in maritime education, while the qualitative findings allowed the researchers to evaluate how these areas are being implemented in practice. This combination of theory and practice makes the research particularly valuable for both academic and practical purposes.

5.5 *Practical Implications of the Findings*

The findings of this research have important practical implications for the future of maritime education. The results suggest that educational institutions need to continue enhancing the integration of green technologies and sustainability principles into their curricula. While progress has been made, more work is needed to ensure that all maritime education programs fully embrace the green transition. This could involve updating curricula, providing professional development for lecturers, and ensuring that students have access to the latest technological advancements in the maritime sector [37], [38].

Interdisciplinary learning should also be prioritized in maritime education. The findings highlight the need for maritime institutions to expand their curricula to include subjects like environmental chemistry, biochemistry, and green chemistry. This would better prepare future seafarers to address the complex environmental challenges facing the maritime industry. Educational institutions should explore ways to integrate these subjects into existing programs and develop new interdisciplinary courses that reflect the interconnected nature of sustainability challenges.

Finally, industry collaboration must be strengthened and formalized. While industry involvement in curriculum development is valuable, the findings suggest that more structured partnerships are necessary to ensure that maritime education remains relevant to industry needs. This could involve establishing formal agreements between educational institutions and maritime companies, as well as creating opportunities for students to engage with industry professionals through internships, workshops, and other practical learning experiences.

5.6 *Suggestions for Future Research*

While this research provides valuable insights into the current state of maritime education, there are several areas that warrant further investigation. Future research could explore the specific barriers to integrating green technologies and interdisciplinary learning into maritime curricula and how these challenges can be overcome. Additionally, research could focus on the effectiveness of industry-academia partnerships in improving maritime education and how these collaborations can be formalized to ensure long-term impact.

Another important area for future research is the development of a comprehensive framework for integrating sustainability principles into maritime education. This could involve identifying best practices for teaching sustainability in maritime contexts and developing tools and resources for educators to incorporate these principles into their teaching. Finally, research could examine the impact of these educational enhancements on the career outcomes of graduates and the broader maritime industry, assessing whether graduates are better equipped to address sustainability challenges in their professional roles.

This research provides a comprehensive analysis of the current state of maritime education, focusing on the integration of green technologies, interdisciplinary learning, industry collaboration, and regulatory knowledge. The findings suggest that while significant progress has been made in these areas, there is still work to be done to fully realize the potential of these educational enhancements. By addressing the challenges identified in this research and continuing to develop more effective educational strategies, maritime institutions can better prepare future seafarers to navigate the complex and evolving landscape of sustainability and technological innovation in the maritime industry.

6 CONCLUSION

This research has provided valuable insights into the current state of maritime education, with a particular focus on enhancing the training of future seafarers through the integration of sustainability, green technologies, interdisciplinary learning, and stronger industry-academia collaborations. The findings suggest that while significant progress has been made in these areas, there remain important gaps and challenges that must be addressed to fully prepare future seafarers for the evolving demands of the maritime industry. The research confirms that green technologies and sustainability principles are being increasingly incorporated into maritime education, yet the integration is still uneven across different institutions. The inclusion of interdisciplinary subjects such as environmental chemistry, biochemistry, and green chemistry has shown potential, but it has not yet

reached its full capacity in many maritime programs. Furthermore, while industry collaboration is a key strength, the study highlights the need for more structured and formalized partnerships to ensure the curricula remain relevant and aligned with the practical demands of the maritime sector.

One of the key implications of this research is the need for educational institutions to prioritize the development of comprehensive, interdisciplinary curricula that integrate sustainability and green technologies. This includes enhancing training in emerging areas such as alternative fuels, energy-efficient maritime technologies, and environmental management. Additionally, maritime educators must be supported with continuous professional development to stay updated on the latest technological advancements and sustainability practices. Another important implication is the need to formalize industry-academia collaborations. While existing partnerships are valuable, there is a need for more strategic and structured alliances between maritime institutions and industry stakeholders. Such partnerships can help ensure that the education provided is closely aligned with industry needs, providing students with more relevant and hands-on learning experiences.

Finally, this research underscores the importance of enhancing regulatory knowledge within maritime education, particularly in the context of sustainability. Future research should explore further how maritime education can better prepare students to understand and navigate the complexities of international regulations, environmental standards, and sustainability requirements. This research highlights the critical role of integrating sustainability, interdisciplinary learning, and industry collaboration into maritime education to ensure that future seafarers are equipped to meet the challenges of a rapidly evolving maritime industry. By addressing the gaps identified in this study, educational institutions can better prepare their graduates for successful careers in a sustainable and technologically advanced maritime sector.

7 RESEARCH LIMITATION AND FUTURE RESEARCH AGENDA

While this research provides valuable insights into the enhancement of maritime education for future seafarers, it is not without limitations. One key limitation is the relatively small sample size, consisting of only 10 participants from specific fields within the maritime industry. Although the diversity in expertise provided rich qualitative data, a larger and more varied sample would offer a broader understanding of the perspectives on maritime education. Furthermore, the research focused primarily on the viewpoints of industry professionals, lecturers, and graduates from a limited geographical scope, which may limit the generalizability of the findings to global contexts.

Additionally, the study primarily relied on qualitative interviews, which, while rich in detail, may be influenced by subjective interpretations and biases. Future research could benefit from a mixed-methods approach, combining qualitative interviews with quantitative surveys to provide a more comprehensive analysis of maritime education's effectiveness.

Future research could explore the impact of specific green technologies and sustainability practices on the maritime curriculum. Investigating the effectiveness of current industry-academia partnerships and their direct impact on curriculum development and students' career readiness would also be valuable. Moreover, research into the development of competency-based frameworks for maritime education, incorporating the latest regulatory and sustainability standards, would contribute significantly to preparing future seafarers for the evolving maritime industry. Finally, cross-cultural studies that examine maritime education in different regions could provide insights into global best practices.

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