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Virtual Technology Utilization, Skills Development, and Maritime Regulatory Compliance: Basis for a Cadet Competency Enhancement Framework

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Abstract

The continuing digital transformation of maritime operations has increased the need for training approaches that develop technical competence, adaptive decision-making, and regulatory readiness among future maritime professionals. This study examined the relationships among virtual technology utilization, skills development, and maritime regulatory compliance as the basis for developing a Cadet Competency Enhancement Framework. A descriptive-correlational design was employed using an adapted and modified questionnaire covering virtual reality, augmented reality, and digital twin applications; technical, cognitive, and soft skills; and environmental, safety, and emergency preparedness compliance. Descriptive statistics and Spearman rho correlation were used to analyze the data. The findings indicated moderate utilization of virtual technologies, moderate development of cadets' technical, cognitive, and soft skills, and moderate levels of maritime regulatory compliance. Strong and statistically significant positive relationships were observed between virtual technology utilization and skills development, between virtual technology utilization and maritime regulatory compliance, and between skills development and maritime regulatory compliance. These findings indicate that technology-enabled training, competency formation, and compliance readiness are closely interconnected within maritime education and professional preparation. Based on the empirical results, a Cadet Competency Enhancement Framework was developed to integrate immersive technologies with structured competency development and regulatory preparation. The study provides practical implications for maritime institutions seeking to strengthen technology-enabled training systems, workforce capability development, operational readiness, and compliance-oriented learning practices.

Keywords: *virtual technology; digital twin; skills development; maritime regulatory compliance; competency development; operational readiness*

1. Introduction

The maritime industry is undergoing substantial technological transformation as vessels, operational systems, navigation technologies, and regulatory requirements become increasingly sophisticated. These developments create corresponding pressures on maritime education and training institutions to prepare cadets not only with theoretical knowledge but also with the technical, cognitive, and interpersonal capabilities required for contemporary shipboard operations. Traditional classroom instruction remains important for establishing foundational knowledge; however, the increasing complexity of maritime work has intensified the need to connect theoretical preparation with realistic operational experience. This challenge is particularly important because many shipboard situations involve hazardous, costly, or difficult-to-replicate conditions that cannot be routinely reproduced through conventional training.

Virtual technologies provide one mechanism for narrowing this gap between classroom preparation and operational practice. Virtual Reality (VR), Augmented Reality (AR), and related simulation technologies can recreate operational environments in which learners practice procedures, interact with equipment, encounter simulated hazards, and respond to realistic scenarios without the risks associated with actual vessel operations (Christopoulos & Stylios, 2024). Within higher education, immersive technologies have also been recognized for their potential to strengthen experiential learning and support instructional practices that require greater learner interaction and engagement (Bouterraka, 2024). The relevance of these technologies is particularly pronounced in maritime training, where competence depends substantially on the ability to translate knowledge into appropriate action under operational constraints.

The significance of technological innovation in maritime training extends beyond the acquisition of new instructional equipment. Its organizational value depends on whether technological resources contribute meaningfully to the development of competencies required in professional practice. Maritime training operates within an internationally regulated environment in which competency development must remain aligned with standards governing the preparation and performance of seafarers. The Standards of Training, Certification and Watchkeeping for Seafarers (STCW), including the 2010 Manila Amendments, emphasizes competency-based preparation, simulation-supported training, and continuing assessment of maritime competencies (International Maritime Organization [IMO], 2021). Consequently, the adoption of emerging technologies should be understood not merely as educational modernization but as part of a broader institutional capability to produce personnel who are technically competent, operationally prepared, and capable of meeting regulatory expectations.

This presents an important management and implementation challenge for maritime institutions. Technological innovation requires investment in infrastructure, instructional systems, faculty capability, and curriculum integration. The cost of developing and maintaining advanced virtual environments may constrain adoption, particularly among institutions with limited resources (Bachmann et al., 2024). At the same time, the rapidly changing technological requirements of the maritime sector require training institutions to adapt without compromising compliance with established international competency standards (Kim et al., 2021). Technology utilization must therefore be assessed not only according to the availability or presence of VR, AR, and simulation applications but also according to whether their use is associated with measurable dimensions of cadet competency and professional preparedness.

Among the emerging technologies with potential relevance to maritime capability development are Digital Twin applications. Alongside VR and AR, Digital Twin technologies provide increasingly realistic representations of operational systems and environments, creating opportunities for repeated practice, system familiarization, feedback, and scenario-based learning. The strategic relevance of these technologies lies in their capacity to integrate technological exposure with competency development. For maritime institutions, therefore, the pertinent question is not simply whether advanced technologies are being introduced, but whether their utilization corresponds with stronger technical abilities, cognitive capabilities, soft skills, and readiness to operate within a highly regulated environment.

Cadet competency itself is multidimensional. Technical skills enable future maritime professionals to perform operational tasks and interact appropriately with shipboard equipment and systems. Cognitive skills support judgment, problem-solving, situational awareness, and decision-making, particularly when conditions are uncertain or rapidly changing. Soft skills—including communication, teamwork, adaptability, and leadership—support coordinated performance in shipboard environments where personnel frequently work in multicultural teams and under demanding conditions. The development of these competencies represents an important organizational outcome of maritime training because institutional effectiveness is ultimately reflected not simply by curriculum delivery but by the preparedness of graduates to function within professional operations.

Regulatory compliance represents an equally important dimension of this preparedness. Maritime operations are governed by extensive requirements concerning environmental protection, occupational and operational safety, and emergency preparedness. Cadets must consequently be prepared to translate regulatory knowledge into appropriate operational behavior. Effective competency development therefore requires a degree of integration among technological exposure, practical capability formation, and regulatory readiness. Examining virtual technology utilization together with skills development and maritime regulatory compliance can provide a more integrated understanding of how technological innovation may contribute to workforce preparation.

Despite the increasing application of virtual technologies in maritime education, an important empirical issue remains: technological utilization does not necessarily establish that corresponding competency and compliance outcomes are being developed. Much of the institutional value of technology adoption depends on whether such technologies operate as meaningful capability-building mechanisms rather than as supplementary instructional tools. The present study therefore positions virtual technology utilization within a broader capability-development system encompassing workforce competency and regulatory readiness.

Objectives of the Study

This study aimed to determine the relationship among virtual technology utilization, skills development, and maritime regulatory compliance as the basis for designing a Cadet Competency Enhancement Framework. Specifically, it aimed to: (1) determine virtual technology utilization in terms of Virtual Reality, Augmented Reality, and Digital Twin applications for vessel operations; (2) assess cadets' skills development in terms of technical, cognitive, and soft skills; (3) describe maritime regulatory compliance in terms of environmental compliance, safety compliance, and emergency preparedness; (4) test the significant relationships among virtual technology utilization, skills development, and maritime regulatory compliance; and (5) develop a Cadet Competency Enhancement Framework based on the findings of the study.

2. Review of Related Literature

2.1 Virtual and Immersive Technologies as Capability-Enabling Systems

Digital transformation has expanded the technological resources available for maritime education and professional preparation. Virtual Reality, Augmented Reality, and Digital Twin technologies provide simulated or digitally enhanced environments in which learners can interact with operational scenarios without being exposed to the risks and costs associated with actual vessel operations. In maritime applications, virtual environments can recreate bridge operations, engine-room conditions, emergencies, equipment failures, and other shipboard situations, enabling repeated practice within controlled settings (Christopoulos & Stylios, 2024).

VR provides immersive environments that can increase learner interaction with complex systems and operational processes. Research on maritime and higher-education applications indicates that immersive technologies can support engagement, experiential learning, situational awareness, and practical understanding when properly incorporated into training activities (Bačnar et al., 2025; Bouterraka, 2024; Kazura et al., 2024). Simulation realism is especially important because the educational value of immersive systems depends not merely on technological novelty but on their capacity to reproduce meaningful situations in which learners can make decisions and perform operational tasks. Christopoulos and Stylios (2024) associated simulation-based maritime training with situational awareness and learning outcomes, while Makransky and Petersen (2021) explained that immersive environments can support psychological presence and learner agency. More broadly, thematic reviews of presence and cognitive load in extended reality caution that greater immersion does not automatically translate into stronger learning outcomes, underscoring the need for deliberate instructional design around VR use (Atento, Quinto, et al., 2026). VR has also been applied to emergency and rescue scenarios, allowing users to practice procedures that would otherwise be hazardous or difficult to replicate (Vukelic et al., 2023). The extent to which learners benefit from such immersive exposure may also depend on individual technology literacy, motivation, and acceptance, as comparable research among technical and allied-health students has linked emerging-technology literacy with academic motivation and linked perceived learning value with learners' acceptance of technology-enabled instruction (Atento, Malolos, et al., 2026; Maranan et al., 2026).

AR differs from fully immersive VR by superimposing digital information on physical environments. This allows users to interact simultaneously with real-world contexts and digitally generated information through smartphones, tablets, or specialized devices (Sharma & Kapoor, 2024). In maritime settings, AR can support equipment familiarization, navigation, procedural learning, and situational awareness. Houweling et al. (2024), for example, examined the relationship between AR displays and operator situation awareness, while Rezaldi et al. (2022) explored AR-supported maritime navigation. These applications demonstrate how digital overlays can provide operational information without completely separating learners from their physical environment.

Digital Twin technology adds another dimension by creating digital representations of physical assets or systems that can reflect actual or simulated operating conditions. In maritime contexts, Digital Twins can represent vessels, propulsion systems, navigation systems, and other operational environments, thereby supporting realistic practice and system-level understanding (Madusanka et al., 2023). Studies have associated Digital Twin applications with feedback, troubleshooting, experiential learning, and situational awareness (Altosole et al., 2022; Li et al., 2022). However, successful deployment also depends on institutional capability. High implementation costs, technological infrastructure, cybersecurity requirements, faculty preparation, and continuing technical support remain relevant constraints (Bachmann et al., 2024). Thus, technology adoption in maritime institutions represents an organizational capability issue as much as an instructional one.

2.2 Maritime Competency Development and Workforce Readiness

Competency development in maritime education extends beyond the acquisition of technical knowledge. Contemporary maritime work requires personnel who can perform operational procedures, interpret complex information, make sound decisions, communicate effectively, and adapt to changing circumstances. Consequently, competency development encompasses technical, cognitive, and soft skills that collectively contribute to professional and operational readiness. The quality of maritime preparation therefore depends substantially on opportunities for practical exposure, simulation, guided practice, and meaningful application of theoretical knowledge.

Technical skills refer to the operational abilities required to perform maritime tasks safely and effectively, including navigation, machinery operation, maintenance, equipment use, safety procedures, and emergency response. Hjellvik and Mallam (2023) emphasized the value of structured and repeated simulator training in progressing from knowledge acquisition to practical skill performance. Similarly, Abid et al. (2025) identified training design and implementation as important factors in effective maritime simulator training. The institutional environment also matters: Karahalil et al. (2025) noted that resources, regulatory requirements, cultural conditions, and instructional practices can affect how simulator-based maritime education is implemented. Comparable patterns have been reported in other high-stakes technical training contexts: structured simulation-based learning has been positively associated with perceived clinical competency among nursing students (Cabanban et al., 2026), while training-content relevance and institutional support have similarly been linked to trainees' perceived training effectiveness among vocational technical inspectors (Xiaomei & Atento, 2026). These findings indicate that technical competency is shaped not only by individual learner capability but also by the organizational quality and consistency of the training system.

Practical experience remains an essential complement to technological and classroom-based instruction. Cadetship programs connect institutional preparation with actual professional environments and allow cadets to progressively assume operational responsibilities. However, learning opportunities and mentoring quality can vary across placements and vessel assignments (Popa et al., 2023). More broadly, a continuing concern in maritime preparation is the potential misalignment between institutional outcomes and changing industry expectations. Barasa et al. (2025) argued for stronger alignment between maritime education and evolving sectoral requirements. This concern reflects a broader pattern in which misalignment among qualification standards, curricula, and sectoral requirements can undermine coherent workforce preparation across educational systems more generally (Quinto et al., 2026).

Cognitive competencies are central to maritime performance. These include information processing, reasoning, judgment, problem-solving, decision-making, and situational awareness. Such capabilities become especially important when personnel operate complex systems under uncertain or rapidly changing conditions. Research has linked cognitive and decision-making deficiencies to maritime human-factor risks, emphasizing the need for personnel who can recognize hazards and make appropriate operational judgments (Salimi et al., 2025). Simulator-based training may support this development by allowing learners to connect conceptual understanding with repeated decision-making and performance evaluation (Hjellvik & Mallam, 2023).

Soft skills complement technical and cognitive capabilities. Communication, teamwork, leadership, adaptability, stress management, and problem-solving are particularly important aboard vessels, where personnel operate within coordinated and often multicultural crews. Hamidi et al. (2024) identified leadership, adaptability, problem-solving, and communication among the competencies expected of maritime cadets, while Zheliaskov et al. (2024) emphasized teamwork, resilience, and initiative within professional maritime competence. These capabilities contribute not only to individual employability but also to safe and coordinated operational performance.

2.3 Maritime Regulatory Compliance and Operational Preparedness

Maritime operations take place within an extensive international regulatory environment intended to promote safety, environmental protection, and consistent professional standards. Among the principal regulatory instruments are the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, the International Safety Management Code, the Safety of Life at Sea Convention, and environmental requirements associated with MARPOL. These frameworks establish expectations for competency, safety management, pollution prevention, and operational behavior, making regulatory readiness an essential component of maritime workforce capability (Mišković & Wang, 2025). Within the Philippine maritime sector specifically, compliance outcomes have also been linked to human factors and organizational practices in the implementation of quality management systems within maritime manning operations (Gamasan & Atento, 2026).

Environmental compliance requires both institutional mechanisms and individual operational awareness. Maritime personnel must understand and apply requirements related to pollution prevention, waste management, emissions, ballast water, and other environmental impacts associated with shipping. Masodzadeh et al. (2022) emphasized the role of regulatory and policy frameworks in supporting lower-carbon shipping, while Saliba et al. (2022) highlighted the importance of governance mechanisms in controlling shipping-related pollution. Wang et al. (2022) demonstrated the environmental consequences associated with ballast-water-mediated species transfer. These studies suggest that environmental regulation becomes effective only when requirements are translated into organizational practices and individual behaviors.

Safety compliance similarly extends beyond formal knowledge of regulatory provisions. Maritime personnel must consistently apply safety procedures during routine and hazardous activities. Because shipboard operations involve fire, collisions, machinery failures, hazardous cargo, and adverse environmental conditions, cadets must develop safety-oriented behaviors before assuming full professional responsibilities. Compliance must therefore be understood as demonstrated capability rather than regulatory familiarity alone.

Emergency preparedness further demonstrates the connection between regulation and performance. Effective preparedness involves understanding emergency procedures, participating in realistic drills, knowing assigned responsibilities, communicating effectively, and acting appropriately during fire, flooding, collision, grounding, abandonment, and other emergencies. Aly et al. (2023) highlighted the need for emergency training requirements to reflect the complexity of contemporary maritime emergencies, while Corpuz et al. (2024) examined the contribution of onboard safety drills to emergency response preparedness among Filipino seafarers. Repeated simulation and drill exposure can familiarize personnel with emergency roles, although effective preparedness also requires judgment and adaptation when conditions depart from routine scenarios.

2.4 Technology Utilization, Competency Formation, and Compliance Readiness

The literature suggests that virtual technology utilization, competency development, and regulatory compliance should not be regarded as separate institutional concerns. Virtual technologies create environments in which technical procedures, decision-making, communication, and emergency responses can be practiced repeatedly. Competency frameworks establish the abilities that maritime personnel are expected to demonstrate, while regulatory standards define the safety, environmental, and operational requirements within which those competencies must ultimately be exercised.

This integration is evident in the assessment capabilities of simulation technologies. Virtual environments can record user actions and support feedback and competency documentation, which can be aligned with institutional learning outcomes and STCW-related expectations (Tusher et al., 2024). Simulation-based learning also permits repeated exposure to operational situations in which learners must interpret information, perform technical tasks, and evaluate the consequences of their decisions (Christopoulos & Stylios, 2024). Such mechanisms are significant because competency formation depends not only on theoretical knowledge but also on opportunities to translate that knowledge into observable performance.

Different immersive technologies may contribute to this integration in complementary ways. VR can reproduce hazardous or unusual situations in safe environments, including collaborative emergency exercises that require technical and non-technical responses (Vukelic et al., 2023). AR can support situational awareness by providing relevant information while users continue interacting with their physical environment (Houweling et al., 2024). Digital Twins can provide system-level representations and repeated operational feedback, enabling learners to understand how decisions affect equipment or processes (Altosole et al., 2022; Li et al., 2022).

From an organizational perspective, the potential contribution of immersive technology depends on implementation quality. Technology acquisition alone does not guarantee capability development. Appropriate infrastructure, instructor preparation, curriculum integration, assessment mechanisms, technical support, and institutional resources remain necessary for technology-enabled training to generate meaningful outcomes (Bachmann et al., 2024; de Oliveira et al., 2022; Karahalil et al., 2025).

2.5 Synthesis and Research Gap

The reviewed literature establishes three broad conclusions. First, VR, AR, Digital Twin applications, and maritime simulation technologies can provide controlled and realistic environments for experiential learning, repeated practice, feedback, situational awareness, and operational familiarization (Christopoulos & Stylios, 2024; Kazura et al., 2024; Li et al., 2022; Madusanka et al., 2023). Second, professional maritime readiness requires a combination of technical, cognitive, and soft skills rather than technical proficiency alone (Hamidi et al., 2024; Hjellvik & Mallam, 2023; Zheliaskov et al., 2024). Third, environmental protection, safety, and emergency preparedness require personnel who can translate regulatory knowledge into competent operational behavior (Aly et al., 2023; Corpuz et al., 2024; Mišković & Wang, 2025).

However, these bodies of literature are frequently treated independently. Studies on immersive technologies tend to emphasize adoption, usability, engagement, simulation fidelity, or instructional applications; competency research tends to focus on technical and non-technical capability development; and regulatory literature commonly concentrates on safety, environmental governance, or compliance requirements. Comparatively less integrated empirical evidence examines virtual technology utilization, multidimensional skills development, and maritime regulatory compliance within a single analytical framework.

The present study addresses this gap by examining these three domains simultaneously among maritime cadets. Rather than treating technology adoption as an end in itself, the study positions technological utilization within a broader capability-development system encompassing technical, cognitive, and soft skills together with environmental, safety, and emergency preparedness. The resulting Cadet Competency Enhancement Framework therefore seeks to connect technological innovation, workforce capability, and regulatory readiness within an integrated institutional approach to maritime professional preparation.

3. Methodology

3.1 Research Design

The study employed a descriptive-correlational research design to examine virtual technology utilization, skills development, and maritime regulatory compliance among maritime cadets. The descriptive component was used to determine the reported levels of the three major constructs and their respective dimensions, while the correlational component examined the statistical relationships among them. The variables were observed without experimental manipulation, and the empirical findings subsequently served as the basis for developing the Cadet Competency Enhancement Framework.

3.2 Participants of the Study

The respondents were maritime cadets from three private maritime higher education institutions affiliated with the Norwegian Ship Owners Association. Eligibility was limited to cadets who had completed onboard training, ensuring that respondents possessed practical exposure to vessel operations and maritime training environments. Their experience provided an appropriate basis for assessing the utilization of Virtual Reality, Augmented Reality, and Digital Twin applications; the development of technical, cognitive, and soft skills; and maritime regulatory compliance.

3.3 Sampling Technique

The study employed stratified random sampling to obtain representation from the participating maritime institutions and relevant respondent groups. The original study deliberately balanced representation across the participating institutions to reduce disproportionate influence from any single institution and to support comparability of respondent assessments.

3.4 Research Instrument and Measures

Data were collected using an adapted and modified questionnaire organized around the three principal constructs of the study. Virtual technology utilization comprised Virtual Reality, Augmented Reality, and Digital Twin applications. The indicators for these dimensions were adapted from Bačnar et al. (2024), Küçük et al. (2014), and Lalou et al. (2025). Skills development comprised technical skills, cognitive skills, and soft skills, with indicators adapted from Tavacıoğlu et al. (2020) and Hamidi et al. (2024). Maritime regulatory compliance comprised environmental compliance, safety compliance, and emergency preparedness, drawing from Mišković and Wang (2025) and Corpuz et al. (2024). Each dimension consisted of five indicators measured using a four-point response format.

The instrument underwent expert validation and pilot testing before the main data collection. Pilot testing involved 30 maritime cadets who had completed onboard training. Reliability was examined using Cronbach's alpha, and all nine dimensions demonstrated high internal consistency, with coefficients ranging from .930 to .976.

Table 1. *Internal Consistency of the Research Instrument*

Construct	Dimension	Cronbach's α	Items
Virtual Technology Utilization	Virtual Reality	.930	5
	Augmented Reality	.951	5
	Digital Twin Application	.962	5
Skills Development	Technical Skills	.938	5
	Cognitive Skills	.941	5
	Soft Skills	.959	5
Maritime Regulatory Compliance	Environmental Compliance	.964	5
	Safety Compliance	.976	5
	Emergency Preparedness	.975	5

All coefficients exceeded .90, indicating very high internal consistency among the items used to measure each dimension.

3.5 Data Gathering Procedure

The research instrument underwent review and validation involving the research adviser, statistician, relevant institutional evaluators, and field experts. Following validation and pilot testing, permission was obtained from the participating maritime higher education institutions before questionnaire administration. Data were collected electronically through Google Forms. Participants were informed of the purpose of the study before responding, after which the collected data were prepared for statistical analysis.

3.6 Data Analysis

Descriptive statistics, particularly weighted means and ranking, were used to determine the levels of virtual technology utilization, skills development, and maritime regulatory compliance. Normality was assessed using the Shapiro–Wilk test, which indicated statistically significant departures from normality. Accordingly, Spearman's rho correlation was used to examine the relationships among virtual technology utilization, skills development, and maritime regulatory compliance. The original study reports the use of JAMOVI version 2.6 for statistical analysis. Mean scores were interpreted using the four-level descriptive categories predefined in the study.

3.7 Ethical Considerations

The study followed principles of voluntary participation, informed consent, confidentiality, anonymity, and data protection. Institutional approval and permission from the participating maritime higher education institutions were obtained before data collection. Participants were informed of the purpose and procedures of the study, their voluntary participation, and their right to withdraw. No identifying information was collected through the questionnaire, and the data were used exclusively for research purposes. Respondents were also assured that participation would not affect their academic standing or employment status.

4. Results and Discussion

4.1 Virtual Technology Utilization

The respondents reported a moderate level of virtual technology utilization across Virtual Reality, Augmented Reality, and Digital Twin applications. Digital Twin applications obtained the highest composite mean (M = 2.94), while both Virtual Reality and Augmented Reality obtained M = 2.92. The overall composite mean for virtual technology utilization was 2.93, interpreted as Moderately Utilized.

Table 2. *Summary of Virtual Technology Utilization, Skills Development, and Maritime Regulatory Compliance*

Construct	Dimension	Mean	Interpretation
Virtual Technology Utilization	Virtual Reality	2.92	Moderately Utilized
	Augmented Reality	2.92	Moderately Utilized
	Digital Twin Applications	2.94	Moderately Utilized
	Overall	2.93	Moderately Utilized
Skills Development	Technical Skills	2.86	Moderately Developed
	Cognitive Skills	2.89	Moderately Developed
	Soft Skills	2.92	Moderately Developed
	Overall	2.89	Moderately Developed
Maritime Regulatory Compliance	Environmental Compliance	2.86	Moderately Compliant
	Safety Compliance	2.89	Moderately Compliant
	Emergency Preparedness	2.87	Moderately Compliant
	Overall	2.87	Moderately Compliant

Within Virtual Reality, the highest-rated item concerned responsiveness and active participation in learning (M = 2.99), whereas learner control and self-paced learning both received the lowest mean of 2.88. For Augmented Reality, the highest-rated indicator concerned the sense of reality created by three-dimensional objects (M = 2.95), while eagerness to attend classes when AR applications were used received the lowest mean (M = 2.88). Digital Twin applications recorded the highest overall utilization among the three technology dimensions; the item describing simulators as pedagogically effective obtained M = 2.96, while training within dangerous accident scenarios received M = 2.91.

Taken collectively, these results indicate that the three forms of virtual technology were already present within the cadets' training experience, but none reached the highest utilization category. The marginally higher rating of Digital Twin applications is consistent with their potential to represent operational systems and support repeated interaction with realistic processes (Jones et al., 2020; Madusanka et al., 2023). For institutional management, the moderate findings suggest that technology acquisition alone does not represent full technological capability; utilization also depends on training design, faculty readiness, technical infrastructure, and integration into operational learning activities (Bachmann et al., 2024; de Oliveira et al., 2022).

4.2 Skills Development of Maritime Cadets

The respondents reported moderate development across all three competency dimensions. Soft skills obtained the highest mean (M = 2.92), followed by cognitive skills (M = 2.89) and technical skills (M = 2.86), producing an overall skills-development mean of 2.89.

Technical skills represented the lowest-rated competency dimension. The strongest technical item was the ability to execute technical shipboard tasks assigned during training (M = 2.88), whereas confidence in performing essential shipboard technical tasks involving navigational or safety equipment received the lowest mean (M = 2.83). This difference is substantively relevant: cadets may be relatively comfortable performing structured tasks within training settings while still reporting lower confidence when competence is framed in terms of actual equipment use. This supports the importance of repeated practical exposure identified by Hjellvik and Mallam (2023).

Cognitive skills were moderately developed, with the highest item relating to decision-making during emergencies (M = 2.91). The lowest-rated items were responding calmly and logically during high-pressure situations and reliance on superiors during critical situations, both at M = 2.87. These findings suggest that decision-making capability was present but had not reached the highest development level. Research has emphasized the importance of cognitive performance and human factors in maritime accident prevention (Salimi et al., 2025).

Soft skills emerged as the strongest of the three competency dimensions. Adaptability to new skills and tools and communication for technical proficiency and safety both obtained M = 2.94, while team cooperation and the more leadership-oriented item involving staff development and performance monitoring received M = 2.89. The findings reinforce the importance of communication, adaptability, teamwork, and leadership within maritime workforce development (Hamidi et al., 2024; Zheliaskov et al., 2024).

4.3 Maritime Regulatory Compliance

Maritime regulatory compliance was assessed at a moderate level, with an overall composite mean of 2.87. Safety compliance ranked highest (M = 2.89), followed by emergency preparedness (M = 2.87) and environmental compliance (M = 2.86).

Environmental compliance represented the lowest-rated compliance dimension. Cadets reported the greatest confidence that environmental procedures taught by their institutions were consistent with industry regulatory requirements (M = 2.90). However, knowledge of correct procedures for handling and disposing of oily waste and bilge water obtained the lowest mean (M = 2.83). This identifies a distinction between confidence in institutional alignment and confidence in concrete environmental procedures and suggests the need for greater practical exposure to pollution-prevention and MARPOL-related operational practices.

Safety compliance obtained the highest mean among the compliance dimensions. Preparedness to follow safety procedures during routine shipboard operations such as cargo handling, mooring, and engine-room checks was the highest-rated item (M = 2.91). The lowest-rated item concerned perceived consistency between safety rules taught and those required by shipping companies and regulations (M = 2.87).

Emergency preparedness produced an overall mean of 2.87. Confidence in following emergency procedures and participation in drills reflecting actual emergency scenarios both obtained M = 2.90, whereas competence in using emergency equipment obtained M = 2.83. The pattern again distinguishes procedural familiarity from equipment-based operational competence. Repeated drills and practical emergency preparation remain central to readiness (Aly et al., 2023; Corpuz et al., 2024).

4.4 Relationships Among Virtual Technology, Skills Development, and Regulatory Compliance

Virtual Technology Utilization and Skills Development

Table 3. *Relationship Between Virtual Technology Utilization and Skills Development*

Virtual Technology	Technical Skills	Cognitive Skills	Soft Skills
Virtual Reality	.868***	.876***	.897***
Augmented Reality	.857***	.872***	.882***
Digital Twin	.879***	.860***	.875***

*Note. Values are Spearman's rho. ***p < .001.*

All nine correlations were positive and statistically significant, ranging from ρ = .857 to .897. The strongest relationship was between Virtual Reality and soft skills (ρ = .897), while the lowest—although still strong—was between Augmented Reality and technical skills (ρ = .857). These results indicate that greater reported utilization of VR, AR, and Digital Twin applications tended to accompany higher levels of technical, cognitive, and soft skills. They do not establish that technology caused the competencies to develop, but they demonstrate a consistent association between technology-enabled training exposure and competency formation. This interpretation is aligned with the literature on immersive learning, which identifies experiential interaction, simulated practice, learner engagement, and embodied experience as mechanisms through which virtual environments may support learning and competency development (Makransky & Petersen, 2021; Radianti et al., 2020).

Virtual Technology Utilization and Maritime Regulatory Compliance

Table 4. *Relationship Between Virtual Technology Utilization and Maritime Regulatory Compliance*

Virtual Technology	Environmental Compliance	Safety Compliance	Emergency Preparedness
Virtual Reality	.871***	.884***	.860***
Augmented Reality	.846***	.863***	.839***
Digital Twin	.874***	.874***	.864***

*Note. Values are Spearman's rho. ***p < .001.*

All relationships between virtual technology utilization and regulatory compliance were positive and statistically significant, ranging from ρ = .839 to .884. The strongest association occurred between Virtual Reality and safety compliance (ρ = .884). Digital Twin applications were strongly related to both environmental and safety compliance (ρ =

.874 for each). These findings indicate that higher utilization of immersive technologies was associated with stronger reported environmental, safety, and emergency preparedness compliance. Virtual environments may be particularly useful because potentially hazardous or difficult-to-replicate situations can be practiced without equivalent real-world risk, consistent with competency-based maritime training principles.

Skills Development and Maritime Regulatory Compliance

Table 5. *Relationship Between Skills Development and Maritime Regulatory Compliance*

Skills Dimension	Environmental Compliance	Safety Compliance	Emergency Preparedness
Technical Skills	.898***	.913***	.907***
Cognitive Skills	.839***	.917***	.907***
Soft Skills	.902***	.917***	.907***

*Note. Values are Spearman's rho. ***p < .001.*

The relationships between skills development and maritime regulatory compliance were the strongest among the three sets of correlations. Coefficients ranged from $\rho = .839$ to .917, with cognitive skills and soft skills both showing their highest association with safety compliance ($\rho = .917$). Technical skills were also strongly associated with safety compliance ($\rho = .913$) and emergency preparedness ($\rho = .907$). This pattern suggests that regulatory readiness is closely connected with competency formation. Compliance with maritime requirements cannot be reduced to knowledge of rules alone; safe and environmentally responsible performance also involves technical execution, situational judgment, communication, teamwork, and appropriate responses to operational conditions. The result supports literature emphasizing the role of technical and non-technical human factors in safe maritime operations (Grech et al., 2019; Mallam et al., 2019).

4.5 Cadet Competency Enhancement Framework

The empirical results served as the basis for the Cadet Competency Enhancement Framework presented in Figure 1. The framework consists of three principal domains: Virtual Technology Utilization, comprising Virtual Reality, Augmented Reality, and Digital Twin applications; Skills Development, comprising technical, cognitive, and soft skills; and Maritime Regulatory Compliance, comprising environmental compliance, safety compliance, and emergency preparedness. The framework links these domains and directs all three toward Cadet Competency Enhancement.

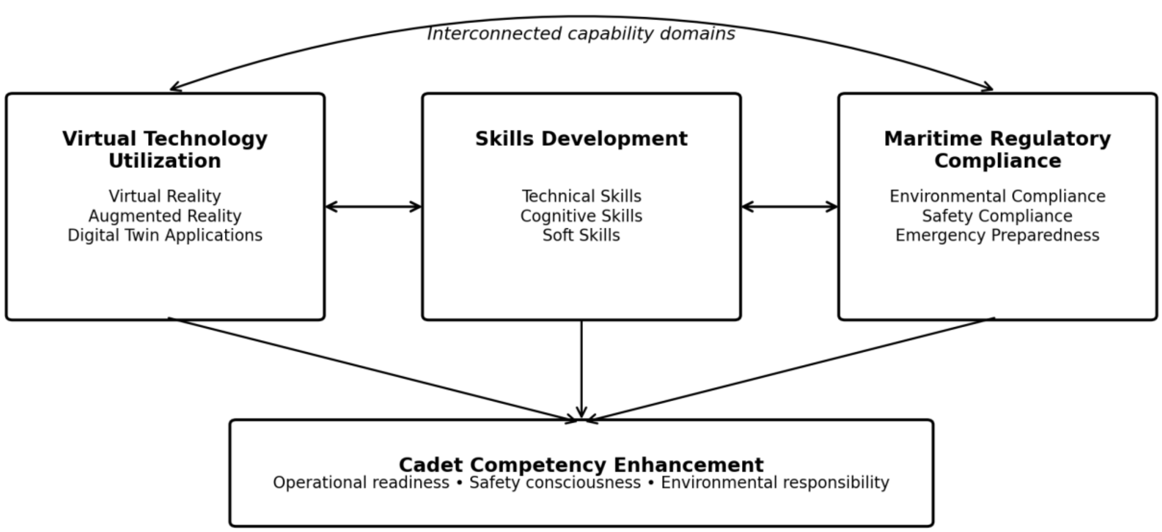

Figure 1. *Cadet Competency Enhancement Framework*

The framework reflects the central empirical pattern of the study: technology utilization, competency formation, and regulatory readiness were individually moderate but strongly interconnected. Virtual technologies provide an enabling training environment; skills development represents the human capability being strengthened; and regulatory compliance establishes the professional and operational standards within which those capabilities must be exercised. The framework positions VR, AR, and Digital Twin applications as instructional catalysts that can be integrated into assessment, practice, application, and debriefing, with targeted enhancement directed toward areas such as technical-task confidence and MARPOL-related environmental handling procedures. Its intended outcome is the preparation of cadets who are operationally ready, safety-conscious, and environmentally responsible.

4.6 Discussion

The findings collectively reveal an important pattern: virtual technology utilization, skills development, and maritime regulatory compliance were all assessed at moderate levels, yet their interrelationships were consistently strong and positive. This combination suggests that the principal issue facing maritime institutions may not be whether these domains are connected, but the extent to which they have been systematically developed and integrated.

The moderate utilization of VR, AR, and Digital Twin technologies indicates that digital transformation is present but not yet fully embedded within the respondents' training experience. Digital Twin applications recorded the highest utilization, although the difference from VR and AR was small. The strongest item-level findings tended to involve interactivity, visualization, pedagogical usefulness, and realistic representation. This pattern is consistent with literature showing that the value of immersive technologies depends not merely on availability but also on instructional design, repeated exposure, institutional support, and meaningful integration into competency-based activities (Bachmann et al., 2024; Christopoulos & Stylios, 2024; de Oliveira et al., 2022). Comparable adaptation challenges have been documented in other technology-dependent training contexts, where educators had to develop adaptive strategies to sustain skills-based instruction despite infrastructural and institutional constraints (Sayas & Quinto, 2026).

The skills results similarly point to a need for balanced workforce development. Soft skills obtained the highest assessment, followed by cognitive and technical skills. Communication and adaptability were comparatively strong, whereas confidence in essential technical shipboard tasks was weaker. This finding is important for organizational capability because professional readiness requires the interaction of technical competence with judgment, communication, teamwork, and adaptability. Maritime operations are socio-technical environments; consequently, neither technical expertise nor interpersonal competency alone is sufficient (Hamidi et al., 2024; Mallam et al., 2019; Zheliaskov et al., 2024).

The regulatory findings reinforce this interpretation. Safety compliance received the highest assessment, while environmental compliance was comparatively lower. The specific weaknesses reported for oily-waste and bilge-water handling and emergency-equipment use indicate that theoretical or procedural familiarity may be more developed than direct operational competence. This distinction is consequential because regulatory compliance ultimately requires actions rather than awareness alone. Environmental standards, safety requirements, and emergency procedures must be converted into consistent performance under actual or simulated operating conditions.

Most importantly, the correlation matrices demonstrate that the three domains function as an interconnected system. Technology utilization was strongly associated with every dimension of skills development and every dimension of regulatory compliance. Skills development was, in turn, strongly associated with environmental, safety, and emergency preparedness compliance. These results support the conceptual logic of the proposed framework while remaining within the limits of a correlational design. The findings establish association rather than causation; nevertheless, the consistency and magnitude of the relationships indicate that institutions should avoid managing technology adoption, workforce competency, and regulatory training as disconnected initiatives.

For institutional strategy, this implies that investment in virtual technology should be accompanied by explicit competency objectives and compliance outcomes. VR, AR, or Digital Twin acquisition has limited organizational value if technologies remain underutilized, disconnected from assessment systems, or insufficiently aligned with operational requirements. Conversely, technology-enabled scenarios can provide environments in which technical execution, decision-making, communication, safety behavior, and emergency response are practiced together. The Cadet Competency Enhancement Framework therefore brings together three areas that are frequently managed separately: technological capability, human competency, and regulatory readiness.

5. Conclusions, Recommendations, and Implications

5.1 Conclusions

The study found that maritime cadets reported a moderate level of virtual technology utilization across Virtual Reality, Augmented Reality, and Digital Twin applications. Digital Twin applications obtained the highest mean among the three dimensions, although all remained within the moderate range. This indicates that virtual technologies have already become part of cadet training experiences but have not yet reached a level that would indicate extensive or fully embedded utilization.

Cadets likewise demonstrated moderately developed technical, cognitive, and soft skills. Soft skills received the highest assessment, followed by cognitive skills and technical skills. The comparatively lower technical-skills result suggests that additional practical and operational exposure remains important for strengthening confidence in performing shipboard tasks and using maritime equipment.

Maritime regulatory compliance was also assessed at a moderate level. Safety compliance received the highest rating, followed by emergency preparedness and environmental compliance. The findings suggest that respondents possessed a reasonable foundation in regulatory requirements but still required stronger practical preparation in specific areas such as environmental handling procedures and emergency-equipment use.

The inferential findings demonstrated strong, positive, and statistically significant relationships among virtual technology utilization, skills development, and maritime regulatory compliance. Because the study employed a descriptive-correlational design, these findings indicate association rather than causation.

Taken together, the findings support the view that technology utilization, competency formation, and regulatory readiness are interconnected dimensions of cadet development. This empirical pattern provided the basis for the Cadet Competency Enhancement Framework, which integrates virtual technologies, technical and non-technical skills, and regulatory compliance toward the development of operationally ready, safety-conscious, and environmentally responsible maritime cadets.

5.2 Recommendations

Maritime higher education institutions should strengthen the systematic integration of Virtual Reality, Augmented Reality, and Digital Twin applications into training activities rather than treating these technologies as occasional supplementary resources. Their use should be connected to specific competency outcomes, practical exercises, assessment activities, and debriefing processes.

Greater emphasis should be placed on technical and operational practice, particularly in areas where respondents demonstrated relatively lower confidence. Training activities may include more frequent simulator sessions, hands-on equipment exposure, scenario-based exercises, and structured opportunities for cadets to apply theoretical knowledge to realistic shipboard situations.

Environmental compliance training should receive additional practical emphasis, particularly in relation to MARPOL-related procedures, oily-waste and bilge-water handling, pollution prevention, and environmental response practices. Emergency-preparedness activities should likewise provide greater opportunities for cadets to handle emergency equipment and participate in increasingly complex simulation scenarios.

Maritime institutions should maintain balanced competency development by integrating technical, cognitive, and soft skills. Communication, teamwork, adaptability, decision-making, and leadership development should be incorporated into technology-enabled exercises alongside operational and technical competencies rather than being addressed as separate learning outcomes.

Implementation of the Cadet Competency Enhancement Framework should involve collaboration among maritime institutions, cadets, educators, training personnel, and maritime industry partners. Future evaluations may employ longitudinal, experimental, or quasi-experimental designs to determine whether structured technology-enabled interventions produce measurable changes in cadet performance beyond the associations established in the present study.

5.3 Implications of the Study

The findings imply that technology investment should be evaluated according to how effectively it contributes to organizational training capability rather than solely according to the availability of equipment or software. Moderate utilization despite strong relationships with competency and compliance suggests that maritime institutions may gain greater value from existing or future technologies when they are systematically integrated into curricula, assessment systems, simulation exercises, and instructor practices.

The study reinforces the importance of a multidimensional competency model. Technical proficiency alone is insufficient for contemporary maritime operations. Cognitive abilities, communication, teamwork, adaptability, and decision-making are strongly connected with regulatory readiness and should therefore be incorporated into competency-development systems alongside technical training. This emphasis on demonstrable, multidimensional competency also parallels a broader movement in professional and continuing education toward skills-based credentialing that values capability over credentials alone, further supporting the practical relevance of a structured competency framework such as the one proposed here (Espelita & Atento, 2026).

Regulatory compliance should not be treated merely as knowledge of maritime rules. The findings indicate that compliance is closely associated with the broader skills needed to perform safely and responsibly. Environmental protection, safety, and emergency preparedness therefore require behavioral and operational competence, including the ability to interpret situations, use equipment correctly, communicate effectively, and act under pressure.

From an innovation-management perspective, the study suggests that the value of VR, AR, and Digital Twin applications lies in their ability to become part of an integrated organizational capability system. Technology adoption should therefore be accompanied by faculty development, infrastructure, scenario design, assessment protocols, technical support, and alignment with industry and regulatory requirements. The Cadet Competency Enhancement Framework offers a practical basis for integrating technological capability, human competency, and regulatory readiness around cadet development.

The strong correlations observed in this study provide a basis for further investigation but should not be interpreted as evidence of causal effects. Future studies may test the framework using intervention designs, comparative institutional samples, longitudinal approaches, or competency-based performance measures.

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