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Marine Engineering in Digital Age: Knowledge, Skills and Attitudes for Autonomous Ships Towards Developing an Enhancement Plan for BS Marine Engineering

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Abstract

The maritime industry is anticipated to undergo a dramatic transformation with the development of autonomous ships, which will increase efficiency, reduce human error, and change crew requirements. As a result, the curriculums of maritime schools need to be updated to incorporate cybersecurity, AI, automation, and remote operations. The competences required to handle autonomous systems will be developed by cadets with the aid of multidisciplinary instruction and sophisticated simulations. Aligning education with future demands also requires cooperation with industry and regulatory agencies.

This descriptive-correlational study determined the necessary skills for shore-based positions and evaluated the instructors' and students' understanding of autonomous ship operations in the field of marine engineering. In addition, it

looked at how engineers, instructors, and students generally felt about ship automation and investigated the connections between attitudes, knowledge, and skills, including contrasting students who received onboard instruction with those who did not. The study also looked into the steps shipping companies took to get crew and engine officers ready for the move to autonomy.

The findings demonstrated that both teachers and students possessed a high level of expertise and proficiency in managing autonomous systems. Though cautious, attitudes toward automation were mainly positive. It was underlined how crucial onboard training is to students' preparation. An enhancement plan was made to strengthen the curriculum of BS Marine Engineering in preparation for students to operate autonomous ships.

Keywords: Marine Engineering, Autonomous Ships, Enhancement Plan, BS Marine Engineering, KSA in Autonomous Ship

Introduction

The maritime industry has witnessed tremendous technical improvements through the years, contributing to better safety, efficiency, and sustainability. The world is in the era of Industry 4.0, or the Fourth Industrial Revolution, a new chapter in human development characterized by extraordinary technological advancement (Xu *et al.*, 2018). Advanced technologies like artificial intelligence (AI), Big Data Analytics (BDA), robotics, Cloud Computing, and the Internet of Things have been introduced into various aspects of society and industry. Literature like that of (Liao & Li, 2022) ^[21] posit that this technological transformation is reshaping human identity, relationships, and work patterns, fundamentally altering how we live and interact with our work environment.

In the maritime industry, several autonomous ship construction projects, such as the Autonomous Spaceport Drone Ship (ASDS) and the Yara Birkeland, rely significantly on technologies associated with Industry 4.0 concepts. *Shipping* in the era of digitalization denotes the new operating paradigm that the maritime transport sector is already moving toward (Ichimura *et al.*, 2022) ^[15].

Shipping companies promote digitalization as the future path for the maritime industry and are actively developing plans. To better understand the industry's direction, it would be beneficial to examine its objectives and strategies in light of digitalization.

According to (Bachari, 2021) ^[3], innovation and progress in the maritime sector occur concurrently with other sectors of the economy. Introducing autonomous ships is one advancement in the maritime industry. As a result, the expansion and diversity of maritime operations have altered the threat landscape, impacting human aspects. Such hazards could relate to traffic,

pollution, illegal immigration, terrorism, navigation, collision avoidance, and environmental hazards.

Additionally, new human-factor concerns exist when operations are switched from an aboard ship approach to remote control (Kim & Mallam, 2020) ^[20]. A big factor is the changing role of seafarers on board and the strategies required to engage seafarers in their transition from traditional shipping to autonomous and smart shipping (Shahbakhsh *et al.*, 2022a) ^[33]. These comprise the knowledge, skills, and education of the Remote-Control Center (RCC) operators in addition to their training. In the face of declining seafarers, developing competency standards for coastal operators of such vessels and providing relevant training will be vital.

The maritime industry has reached a turning point in its history, with autonomous ship technology emerging as a game-changing force in an era defined by the unrelenting march of technological advancement. In order to continue contributing significantly to the marine workforce, the Philippines—known as a global powerhouse in the supply of competent and professional seafarers—must quickly adapt to these rapidly evolving technological environments. The Philippines has a long and rich maritime heritage embedded in its culture. As a result, it has continually supplied the global shipping world with highly skilled and competent seafarers. However, with the introduction of advanced marine technologies and autonomous ships, the demand for adaptation is greater than ever.

For the Philippines, integrating autonomous ship technology is not a matter of choice but a necessity to maintain its standing as a provider of professional maritime experts. This adaptation is vital for ensuring maritime operations' sustainability, efficiency, and safety, and maintaining competitiveness in the global market.

As other maritime nations increasingly embrace autonomous and unmanned vessels, the Philippines must proactively engage with these technologies to stay at the top of the industry. Failure to do so could risk a gradual erosion of the nation's status as a primary source of qualified seafarers, potentially compromising its economic contributions and international standing (Pandeagua, 2019) ^[28].

This introduction paves the way for a more thorough examination of the opportunities and challenges that the Philippines faces as it ventures into the unexplored territory of autonomous ship technology. As we explore deeper into the intricacies of this technological evolution, it becomes clear that the Philippines needs to strengthen its position as a leader in providing qualified and competent seafarers to the international maritime community, not only by keeping up with current developments but also by utilizing the potential of autonomous ships.

The study adapts the O*NET content model, which provides a framework for identifying the most important types of work information and integrating them into a theoretically and empirically sound system.



The O*Net Model, shown in the illustration, provides meaningful information to meet human resource management needs, such as job creation, development of job skills standards, determination of qualification conditions, and determination of job opportunities or training needs for employees. In addition, the information available on this network can be used to describe job descriptions and groupings ((Dybvik *et al.*, 2020).

Working on this model, this study seeks to identify the job requirements in operating autonomous ships, which encompass the skills, knowledge, and education needed to perform such work, and the training skills needed for future seafarers to acquire the experience needed to prepare them to meet the demands of the industry.

Specifically, this study will look into the Marine Engineers' predominant attitude toward Ship Automation and their level of Knowledge of the Requirements for Operating Autonomous Ships, such as Ecology and Environmental Protection, Marine Diesel Engine, Chemistry and Material Properties, Vibration and Hydrostatic, Electrical Engineering, and Thermodynamics; the skillset crucial for marine engineers in performing shore-based operations in autonomous ships; experts' insights on Integration of the Skillset into the BS Marine Engineering curriculum; and the shipping companies' initiatives to prepare their engine officers and crew for autonomous ships.

The findings from this study will provide valuable insights for Maritime Higher Educational Institutions (MHEIs), particularly benefiting academic leaders, curriculum developers, academic assessors, and shipboard training officers, who will assist in updating the curriculum and course content for the Bachelor of Science in Marine Engineering program. The goal is to ensure that maritime education and training remain relevant and responsive to industry needs. Specifically, the study aims to align the competencies developed among Marine Engineering students with the skillset requirements expected of marine engineers in the context of autonomous ships, addressing the evolving demands of the digital landscape in the maritime industry.

This study intends to add to the body of knowledge by illuminating the attitudes of marine engineers toward ship automation, their understanding of the skills necessary to operate autonomous vessels, the skillset considered essential for marine engineers in the digital age, and the steps taken by shipping companies and maritime institutions to match this skill set with the needs of the maritime industry in the current technological environment.

The study seeks to answer the following questions:

1. What is the level of knowledge of Marine Engineering students and Marine Engineering Instructors for the operation of autonomous ships?
2. What skills are essential to performing shore-based operations in autonomous ships?
3. What is the predominant attitude of BS Marine Engineering Students, Marine Engineering instructors, and Marine Engineers towards ship automation?
4. Are there significant differences in the knowledge, skills, and attitudes of Marine Engineering students with and without onboard training?
5. Are there significant relationships among knowledge, skills, and attitudes of Marine Engineering students?
6. For BS Marine Engineering Students, Marine Engineering instructors, and Marine Engineers, how can

- these skills be integrated into the BS Marine Engineering curriculum?
7. What initiatives do the shipping companies implement to prepare their Engine officers and crew for this eventual adaptation to autonomous ships?
 8. What Technological Skills Enhancement Plan can be proposed to enhance the BS Marine Engineering curriculum and the competence of BS Marine Engineering students?

Materials and Method

A descriptive-correlational research design was utilized to examine the significant relationships among the knowledge, skills, and attitudes of marine engineering students, both with and without onboard training. Generally speaking, descriptive correlational research is employed when a researcher wishes to determine the traits of particular populations or establish connections between various variables (Brodowicz, 2024) ^[6].

The descriptive design is appropriate for this study as it aims to determine (1) the level of knowledge of Marine Engineering students and instructors regarding the operation of autonomous ships, (2) the essential skills for performing shore-based operations in unmanned and autonomous ships as identified by Marine Engineering instructors, (3) the predominant attitudes of BS Marine Engineering Students, Marine Engineering Instructors, and Marine Engineers towards ship automation, (4) the differences in the knowledge, skills, and attitudes of marine engineering students with and without onboard training, (5) the relationships among knowledge, skills and attitudes of marine engineering students, (6) the integration of the required skillset into the BS Marine Engineering curriculum, and (7) the initiatives implemented by shipping companies to prepare their engine officers and crew for the adaptation to autonomous ships. Based on this study's results, a proposed Technological Skills Enhancement Plan was designed to enhance the BS Marine Engineering curriculum and BS Marine Engineering students' competence.

The study utilized four sets of researcher-designed survey questionnaires.

Survey for Marine Engineering Instructors. The first survey questionnaire was designed for marine engineering instructors and was composed of the following parts:

Part 1 determined the profile of Marine Engineering instructors based on their sea experience or the number of years they have spent at sea.

Part 2 was designed to assess the knowledge of Marine Engineering instructors regarding the operational requirements for autonomous ships (Bachari-Lafteh & Harati-Mokhtari, 2021; Australian Maritime University, 2019). This part of the survey includes 20 items for *Knowledge of Automated Marine Systems, Pollution Control, and Efficiency*, 12 items for *Knowledge of AI, automation, and IoT in Marine Systems*, 15 items for *Knowledge Of Marine Electrical, Automation, and Propulsion Systems Efficiency*, 10 items for *Knowledge of Material Processing, Vibration Analysis, and Marine Automation*, five items for *Knowledge of Marine Pollution Control, Waste Management, and Decarbonization*, and two items for *Knowledge of Automated Ballast Water and*

Emission Control Systems. Respondents were asked to evaluate their knowledge on a scale of 1 to 5, where 1 = Not Knowledgeable, 2 = Less Knowledgeable, 3 = Moderately Knowledgeable, 4 = Knowledgeable, and 5 = Highly Knowledgeable.

Part 3 aimed to determine the skills essential in performing shore-based operations in autonomous ships from the perspective of Marine Engineering instructors. The Respondents were asked to tick which skills are essential for the following areas: Personal Skills and Competencies, Safety Skills and Competencies, Skills and Competencies to Master Complex Maritime Operations, Sustainability Competencies, Digital Skills and Competencies, and Automation Skills and Competencies. There were ten items to choose from under each area.

Part 4 was designed to determine the prevailing attitudes of Marine Engineering instructors regarding ship automation. This 10-item tool was created using information gathered from multiple sources (Nasur & Boguslawski, 2020 ^[26]; Nautilus Federation, 2018). In this section, Respondents were asked to select the column most accurately reflecting their opinions and feelings about the provided statements. The following scale was utilized: 1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, and 5 = Strongly Agree.

Lastly, Part 5 aimed to gather information from respondents regarding their preferred approach to integrating various skills into the BS Marine Engineering curriculum. Respondents were asked to choose one option from four available choices and provide a rationale for their selection.

Survey for Marine Engineering Students. This research instrument was designed for third-year BS Marine Engineering students who have not yet undergone onboard training and Marine Engineering students who have already completed their onboard training. It consisted of the following parts:

Part 1 aimed to gather the respondents' personal information as BS Marine Engineering Students. Options for With OBT or Without OBT were provided.

Part 2 aimed to identify the level of knowledge of BS Marine Engineering students in the requirements for the operation of autonomous ships (Bachari-Lafteh & Harati-Mokhtari, 2021; Australian Maritime University, 2019). The following areas of knowledge and the corresponding number of items were included in this part of the survey: *Integrating Advanced Systems, Design, and Regulations for Efficient Marine Propulsion* (24 items), *Automating Engine Systems, Heat Transfer, and Water Treatment Processes* (10 items), *Automating Systems to Reduce Pollution and Improve Vessel Efficiency* (10 items), *Optimizing Propulsion, Efficiency, and Environmental Compliance through Advanced Technologies* (8 items), and *Preventing Corrosion While Ensuring Compliance with Maritime Standards* (2 items). The respondents were asked to rate their level of knowledge on a scale of 1 to 5, where 1 = Not Knowledgeable, 2 = Less Knowledgeable, 3 = Moderately Knowledgeable, 4 = Knowledgeable, and 5 = Highly Knowledgeable.

The respondents' knowledge levels were interpreted using the following mean range, verbal description, and interpretation.

Mean Range	Verbal Description	Interpretation
4.20 – 5.00	Very Highly Knowledgeable	Possesses a comprehensive and in-depth understanding of the requirements for operating autonomous ships; is very highly familiar with the core technologies involved in operating autonomous ships.
3.40 – 4.19	Highly Knowledgeable	Has a strong understanding of the operational requirements for autonomous ships; is highly familiar with the core technologies involved in operating autonomous ships
2.60 – 3.39	Moderately Knowledgeable	Has a solid grasp of the requirements for autonomous ship operations; Understands the core technologies involved in operating autonomous ships
1.80 – 2.59	Slightly Knowledgeable	Is a little aware of the requirements for autonomous ships; Has a limited understanding of the core technologies involved in operating autonomous ships.
1.00 – 1.79	Not Knowledgeable	Has no knowledge of the requirements for operating autonomous ships and the core technologies involved in operating them

Part 3 was designed to determine the level of competence of Marine Engineering students on skills essential in performing shore-based operations in unmanned and autonomous ships (Sharma & Kim, 2022 ^[32]; Safety4Sea, 2023). The respondents were asked to identify their level of Skills in the requirements for the operation of autonomous ships by ticking the box corresponding to their answer. This self-survey covered the following skills: *Skill in Sustainable, Automated, and Emergency-Ready Maritime Operations* (24 items), *Adaptable, Innovative, and Safety-Focused Leader in Autonomous Maritime Operations* (18 items), *Skill in*

Automated Ship Systems, Diagnostics, and Safety Monitoring (12 items), *Ensuring Safety, Efficiency, and Maintenance of Digital Maritime Systems* (3 items), and *Proficiency in IT, Data Analysis, and Digital Operations* (2 items). The following scale and verbal interpretation were used: 1 = Not Proficient, 2 = Less Proficient, 3 = Moderately Proficient, 4 = Proficient, and 5 = Highly Proficient.

The following scale and interpretation were used to determine the respondents' skill levels.

Mean Range	Verbal Description	Interpretation
4.20 – 5.00	Highly Proficient	Is highly able to perform the skills required for operating autonomous ships
3.40 – 4.19	Proficient	Has adequate ability to perform the skills required for operating autonomous ships
2.60 – 3.39	Moderately Proficient	Can perform the skills required for operating autonomous ships
1.80 – 2.59	Less Proficient	Limited ability to perform the skills required for operating autonomous ships
1.00 – 1.79	Not Proficient	Cannot perform the skills required for operating autonomous ships

Part 4 was designed to identify the predominant attitude of marine engineering students towards ship automation. This instrument was built based on insights from various literature (Nasur & Boguslawski, 2020 ^[26]; Nautilus Federation, 2018). In this part, the respondents were asked to tick the column that best describes their thoughts and feelings about the statements. The following scale was used:

1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree nor Disagree, 4 = Agree, and 5 = Strongly Agree.

In identifying the predominant attitude of Marine Engineering students, Marine Engineering Instructors, and Marine Engineers towards ship automation, the following mean range, verbal description, and interpretation were used:

Mean Range	Verbal Description	Interpretation
4.20 – 5.00	Enthusiastic	Highly supportive of ship automation; Views automation as a significant advancement that enhances safety, efficiency, and operational ease; Eagerly embraces new technologies and is proactive in learning and adapting to automated systems, believing that automation will improve the working conditions and the overall performance of maritime operations.
3.40 – 4.19	Optimistic	Recognizes the benefits of automation and is generally positive about its impact; Appreciates the improvements in efficiency and safety that automation can bring but may have some reservations or concerns about its implementation; Open to embracing new technologies and is willing to adapt but seeks reassurance regarding the changes
2.60 – 3.39	Neutral	Has mixed feelings about ship automation. Acknowledges technological advancements and their potential benefits but does not have a strong stance on the matter. May be indifferent or cautiously observant, focusing more on the immediate tasks rather than the broader implications of automation.
1.80 – 2.59	Skeptical	Harbors doubts about the efficacy and safety of ship automation; Is concerned about the reliability of automated systems, the potential loss of jobs, and the challenges of adapting to new technologies; Questions the long-term benefits and the impact of automation on seafarers' roles and job security.
1.00 – 1.79	Resistant	Strongly opposes ship automation; Is apprehensive about the changes it brings, fearing job displacement, increased complexity, and loss of traditional skills; Resistance may stem from a deep-seated belief in the value of human experience and judgment in maritime operations and may actively resist or reject the integration of automated systems.

Finally, Part 5 was designed to ask the respondents to identify their preferred method of integrating different skills into the BS Marine Engineering curriculum. The respondents were asked to select only one of the four options and justify their choice.

Survey for Marine Engineers. The third survey questionnaire was intended for marine engineers with at least one year of sea experience. It was composed of three parts. Part 1 for the profile of the respondents, Part 2 to identify marine engineers' predominant attitude towards ship automation, and Part 3 to identify their preferred method of integrating different skills into the BS Marine Engineering curriculum. The same attitudinal survey was used for this group.

Survey for Shipping Company Representatives. The fourth survey questionnaire was intended for shipping company representatives. It aimed to identify the initiatives shipping companies are implementing to prepare their Engine officers and crew for the eventual adaptation to autonomous ships.

Results and Discussion

Table 1 shows that BS Marine Engineering students generally understand the operational requirements for autonomous ships and are highly familiar with the core technologies involved in operating autonomous ships. This high level of knowledge implies that their understanding encompasses their ability to integrate, use, and streamline new automation technologies at sea.

The table compares the level of knowledge of marine engineering students regarding the operation of autonomous ships, distinguishing between those who have undergone On-Board Training (OBT) and those who have not. Students with OBT consistently demonstrate higher mean scores across all knowledge areas, with an overall mean of 4.01, indicating they are highly knowledgeable. Their scores reflect strong competence in integrating advanced systems, automating engine and pollution control systems, optimizing propulsion efficiency, and preventing corrosion, which are critical for autonomous ship operations. The relatively low standard deviations suggest that students with OBT have a consistent and solid grasp of these topics, likely benefiting from practical, hands-on experience that reinforces theoretical learning.

In contrast, students without OBT show lower mean scores in every category, with an overall mean of 3.46, which still falls within the "highly knowledgeable" interpretation but is notably less than their OBT counterparts. The lower scores and higher standard deviations indicate greater variability and less confidence in their knowledge, particularly in complex areas such as system integration and corrosion prevention. This comparison highlights the significant positive impact of OBT on students' understanding and readiness for autonomous ship operations. It suggests that practical training is crucial in deepening knowledge and preparing students more effectively for the technical challenges of modern marine engineering.

Table 1: Level of Knowledge of Marine Engineering Students for the Operation of Autonomous Ships

S. No	Items	With OBT			Without OBT		
		SD	Mean	Interpretation	SD	Mean	Interpretation
1	Integrating advanced systems, design, and regulations for efficient marine propulsion	.60	3.80	Highly Knowledgeable	.81	3.33	Moderately Knowledgeable
2	Automating engine systems, heat transfer, and water treatment processes	.58	4.10	Highly Knowledgeable	.84	3.48	Highly Knowledgeable
3	Automating systems to reduce pollution and improve vessel efficiency	.58	4.13	Highly Knowledgeable	.78	3.62	Highly Knowledgeable
4	Optimizing propulsion, efficiency, and environmental compliance through advanced technologies	.62	3.96	Highly Knowledgeable	.82	3.49	Highly Knowledgeable
5	Preventing corrosion while ensuring compliance with maritime standards	.58	4.04	Highly Knowledgeable	.90	3.38	Highly Knowledgeable
	Overall	.52	4.01	Highly Knowledgeable	.76	3.46	Highly Knowledgeable

Note: 4.20 – 5.00 Very Highly Knowledgeable, 3.40 – 4.19 Highly Knowledgeable, 2.60 – 3.39 Moderately Knowledgeable, 1.80 – 2.59 Slightly Knowledgeable, 1.00 – 1.79 Not Knowledgeable

The overall mean of 4.01 (SD=.52) for students with OBT, and 3.46 (SD=.76) for students without OBT, interpreted as "highly knowledgeable," shows that the marine engineering students possess a deep and wide understanding of the technical, operational, and regulatory needs required to operate Maritime Autonomous Surface Ships (MASS).

Moreover, the results indicate that the standard deviation (SD) values for students who have undergone onboard training range from 0.52 to 0.62. These relatively low SD values indicate that the knowledge levels among these students are quite consistent; in other words, their responses are closely grouped, revealing strong agreement regarding their understanding of each item. This consistency suggests that having experienced On-board Training not only leads to higher mean scores (reflecting greater knowledge) but also fosters a more uniform learning experience, where most students reach a similar level of competence and confidence in their understanding of autonomous ship operations.

In contrast, the SD values for students without onboard training are notably higher, ranging from 0.76 to 0.90. This wider spread in responses signals greater variability in knowledge levels. Some students may feel quite knowledgeable and confident, while others may feel less certain or knowledgeable about the topics. The higher SD values, therefore, reflect a more diverse range of understanding and confidence among these students, which may be attributed to the absence of the hands-on, practical experience that OBT provides. This lack of uniformity suggests that learning outcomes are less predictable and more varied when students do not engage in onboard training.

Table 2 reveals that marine engineering instructors possess a generally high level of knowledge regarding the operation of autonomous ships, with an overall mean score of 3.75 indicating they are highly knowledgeable. This means they possess a strong understanding of the operational

requirements for autonomous ships and are highly familiar with the core technologies involved in operating them. They demonstrate particularly strong expertise in marine pollution control, waste management, and decarbonization, as well as in marine electrical, automation, propulsion systems, and automated ballast water and emission control systems. This suggests that the instructors are well-prepared to teach critical environmental and technical aspects of autonomous ship operations, reflecting current industry priorities such as sustainability and system efficiency.

The relatively consistent standard deviations across most items indicate a fairly uniform level of knowledge among instructors in these key areas. However, the table also highlights a notable gap in instructors' *knowledge of AI, automation, and IoT in marine systems*, where the mean score drops to 3.20, interpreted as only moderately knowledgeable. Given that AI and IoT technologies are fundamental to the functioning of autonomous ships, this suggests an area where instructors may require additional training or resources to keep pace with technological advancements. Moreover, the higher variability in knowledge related to automated ballast water and emission control systems points to uneven expertise that could benefit

from targeted professional development. Addressing these gaps will be crucial for ensuring that marine engineering education fully equips students with the skills needed to operate and innovate within the rapidly evolving field of autonomous maritime technology.

Specifically, this result provides evidence of the expert knowledge of marine engineering instructors of environmental protection measures and green best practices in seaborne operations. These educators are knowledgeable in recent global standards, including MARPOL and the IMO GHG Strategy, and are equipped to critically examine and apply technologies and methods that minimize the environmental impact of ships. Their experience encompasses familiarity with ballast water treatment, oily water separation, scrubber systems, waste-to-energy solutions, and the use of low- and zero-carbon fuels such as LNG, hydrogen, and ammonia. In addition, they can carry out research, curriculum development, and mentor future engineers to incorporate environmental stewardship into ship design, operation, and management, aligning with global decarbonization goals (International Maritime Organization, 2023^[18]; DNV, 2024).

Table 2: Level of Knowledge of Marine Engineering Instructors for the Operation of Autonomous Ships

S. No	Items	SD	Mean	Interpretation
1	Knowledge of AI, automation, and IoT in marine systems	.46	3.20	Moderately Knowledgeable
2	Knowledge of marine electrical, automation, and propulsion systems efficiency	.64	3.74	Highly Knowledgeable
3	Knowledge of material processing, vibration analysis, and marine automation	.59	3.55	Highly Knowledgeable
4	Knowledge of marine pollution control, waste management, and decarbonization	.52	4.06	Highly Knowledgeable
5	Knowledge of automated ballast water and emission control systems	.77	3.93	Highly Knowledgeable
	Overall	.54	3.75	Highly Knowledgeable

Note: 4.20 – 5.00 Very Highly Knowledgeable, 3.40 – 4.19 Highly Knowledgeable, 2.60 – 3.39 Moderately Knowledgeable, 1.80 – 2.59 Slightly Knowledgeable, 1.00 – 1.79 Not Knowledgeable

The overall mean was 3.75 (SD=.54), interpreted as highly knowledgeable. The result revealed that marine engineering teachers understand the operational requirements for autonomous ships and are highly familiar with the core technologies involved in operating autonomous ships. This means they have an extensive and thorough grasp of the technologies, systems, and operating principles behind Maritime Autonomous Surface Ships (MASS) (Belabyad *et al.*, 2025)^[4]. Their expertise extends beyond the fundamentals to encompass the mastery of intelligent sensing, deep learning, data analysis, digital twin technology, hydrodynamics, propulsion system modeling, and advanced simulation and control techniques for autonomous and remotely operated ships. This refined expertise prepares educators to educate prospective marine engineers not just on the technical functions of autonomous vessels but also on innovation, troubleshooting, and how to cope with the changing dynamics of maritime autonomy to ensure that graduates are set to take on the challenges and prospects brought by the transition towards crewless, data-driven ship operations. (Meštrović *et al.*, 2024)^[24].

Furthermore, interpreting the standard deviations (SD) in Table 2 provides insight into the consistency and agreement among marine engineering instructors regarding their knowledge of autonomous ship operations. The SD values in the table range from 0.46 to 0.77. A low SD (0.46 or 0.52) means most instructors' responses are clustered closely around the mean. This indicates strong agreement and uniformity in their self-assessed knowledge-suggesting that

the group is generally consistent in how knowledgeable they feel about a particular topic. For example, the item with an SD of 0.46 ("Knowledge of AI, automation, and IoT in marine systems") shows that instructors' assessments of their knowledge are very similar. On the other hand, a higher SD (such as 0.77 for "Knowledge of automated ballast water and emission control systems") means the responses are more spread out from the mean. This indicates greater variability in instructors' self-assessed knowledge, which means some feel very knowledgeable, while others feel less so, reflecting less consensus or more diversity in their confidence levels. This implies a more intense training, particularly on "Knowledge of automated ballast water and emission control systems," to ensure a more confident knowledge among marine engineering instructors.

The marine engineering instructors were asked to identify the essential skills for shore-based operations in autonomous ships. Presented in Table 3, under personal skills and competencies, the respondents identified "*Ability to use new working methods*" as the most essential, with a frequency of 17. This result indicates the acknowledgment by marine engineering instructors of the fast-changing character of the shipping industry, particularly with automation and autonomous vessels on the horizon. This skill demonstrates adaptability, innovative openness, and proactive management of new technologies and operational techniques in practice and a willingness to participate in ongoing learning, debug new systems, and adapt quickly to unexpected problems, making maritime professionals both

effective in an environment characterized by perpetual technological change (Belabyad *et al.*, 2025) ^[4].

For safety skills and competencies, the marine engineering instructors have identified “*Adopting the safety mindset of the tanker/gas fleet when working with new fuel types*” as the most essential, with a frequency of 17. This finding reflects a clear awareness of the special dangers and stringent safety measures of using alternative marine fuels like LNG, methanol, hydrogen, and ammonia. This attitude prioritizes a caution culture, careful risk analysis, and rigorous compliance with prescribed safety practices, principles embedded in tanker and gas carrier working practices for many years because of the explosive nature of their cargo. As the shipping industry continues to evolve, frequently more dangerous fuels in pursuit of decarbonization targets, implementing the tanker/gas fleet's safety strategy guarantees that seafarers are on their toes, place hazard detection at the forefront, and are properly prepared for emergency response. This proficiency is essential in preventing accidents, the crew's and the ship's safety, and regulatory compliance because novel fuels present unfamiliar hazards demanding equal vigilance and specialized education as conventional tanker handling. (Kaspersen *et al.*, 2022 ^[19]; IMarine EngineeringST, 2024 ^[16]; SAFETY4SEA, 2022).

On the other hand, on skills and competencies to master complex maritime operations, the marine engineering instructors identified “*Ability to perform safe vessel and equipment maintenance with more hazardous fuels on board*” as the most essential, with a frequency of 17. The result represents an increased recognition of marine engineering instructors of the distinct risks involved in the use of alternative marine fuels like hydrogen, ammonia, and methanol. These fuels present novel safety risks such as flammability, toxicity, and corrosiveness that need proprietary maintenance operations, thorough risk analysis, and strict compliance with safety management practices. Crew members should be proficient in hazard identification, donning the right protective equipment, and executing emergency response during maintenance work. This ability also includes knowing the design and operation of fuel systems, having knowledge of new fuel properties, and ensuring that maintenance is done without jeopardizing vessel or crew safety. As the market turns to substitute fuels, giving priority to this skill means that staff can efficiently avert accidents, react to crises, and maintain regulatory compliance, hence enabling the safe and sustainable uptake of new energy supplies in marine operations (BIMCO, 2024; IMarine EngineeringST, 2024 ^[16]; SAFETY4SEA, 2024 ^[30]).

Table 3: Skills Essential for Performing Shore-Based Operations in Autonomous Ships according to Marine Engineering Instructors

S. No	Items	Total	
		Frequency	Percent
	Personal Skills and Competencies		
1	Ability to make use of new working methods	17	85
2	Ability to learn new skills as technology changes	2	10
5	Innovation mindset to understand business development and take advantage of digital technology	1	5
	Total	20	100
	Safety Skills and Competencies		
1	Adopting the safety mindset of the tanker/gas fleet when working with new fuel types	17	85
2	Ability to implement updated emergency preparedness procedures such as first aid, fire detection, and firefighting	3	15
	Total	20	100
	Skills and Competencies to Master Complex Marine Operations		
1	Ability to perform safe vessel and equipment maintenance with more hazardous fuels on board	17	85
2	Ability to handle the digital and manual systems for bridge, deck, engine, maneuvering, and propulsion that are introduced with the new fuel technology	2	10
5	Ability to operate hydraulic components and pneumatic equipment	1	5
	Total	20	100
	Sustainability Competencies		
1	Emission monitoring and documentation	18	90
2	Environmental economics and the use of performance management systems	2	10
	Total	20	100
	Digital Skills and Competencies		
1	IT and digital skills	16	80
3	Ability to operate equipment using digital controls	3	15
4	Ability to solve tasks digitally through operations monitoring and system management	1	5
	Total	20	100
	Automation Skills and Competencies		
1	Managing automation failure with onshore support	15	75
2	Detailed knowledge of and proficiency in the use of automated systems and the ability to monitor and correct their function (s/c)	1	5
3	Ability to diagnose defects and rectify them via automated systems	3	15
4	Operation of electrical systems	1	5
	Total	20	100

On sustainability competencies, the respondents identified “Emission monitoring and documentation” as the most essential (F=18). This result highlights the importance of monitoring, recording, and reporting ship emissions. Competency in this area maintains adherence to increasingly stringent global and regional regulations, including the EU MRV system and the IMO DCS, which mandate ships to report and monitor CO₂, methane, and nitrous oxide emissions, as well as fuel consumption and other voyage factors (American Bureau of Shipping, 2025). Ultimately, this skill is essential for fostering a culture of compliance, transparency, and continuous improvement in maritime environmental performance (Sinay Maritime Data Solution, 2023) [34].

For digital skills and competencies, the marine engineering instructors identified “IT and digital skills” as the most essential (F=16). This result reveals that marine engineering instructors recognize the move by the industry toward digitalization and the growing use of cutting-edge technologies in vessel operations. The skills help marine engineers effectively harness and handle digital tools, data analytics, automation systems, and networked devices, which are now an integral part of ensuring ship performance, optimizing efficiency, and ensuring safety (Seaman Solutions, 2025; Yadav, 2025) [31, 36]. Ultimately, prioritizing IT and digital skills ensures that marine engineers remain relevant, resilient, and capable in a rapidly evolving maritime landscape (Yadav, 2025) [36].

Finally, for automation skills and competencies, the respondents identified “Managing automation failure with onshore support” as the most essential. The result highlights the acute requirement for expertise in managing system failures on increasingly automated and autonomous ships. With diminished or even a complete absence of crew on board, the functionality of coordinating with Onshore Operation Centers (OOCs) assumes significance in ensuring safety and operational continuity in case of automation malfunctioning. This capability represents the maritime sector's turn toward distant management. It showcases the significance of blending human experience with digital assistance systems to overcome contemporary ship operations' complexities (Adnan & Perera, 2024) [1].

Table 4 reveals that students with OBT are generally proficient in skills related to operating autonomous ships. This means that under supervision, they have adequate ability to perform the skills required for operating autonomous ships. The findings indicate that these students

have adequate skills in sustainable, automated, and emergency-ready maritime operations and automated ship systems, diagnostics, and safety monitoring, ensuring the safety, efficiency, and maintenance of digital maritime systems. Additionally, these students are adaptable, innovative, and safety-focused leaders in autonomous maritime operations and demonstrate proficiency in IT, data analysis, and digital operations. Most importantly, their emphasis on safety ensures that they adhere to stringent safety protocols, are situationally aware, and actively assess and mitigate risks unique to autonomous operations. This combination of skills is crucial to ensure operational efficiency and safety of life, cargo, and vessels in increasingly automated maritime environments (Belabyad *et al.*, 2025 [4]; BMT, 2024). The results imply that having experienced on-board training enables such students to gain hands-on experience with information systems technology, including simulation packages and automated identification systems, that enhance their working proficiency, emergency preparedness, and use of complex shipboard systems. (Komba, 2024).

On the other hand, students without OBT are generally moderately proficient, which means that they have a moderate ability to perform skills required for operating autonomous ships. They rated themselves highest on “Skill in automated ship systems, diagnostics, and safety monitoring.” In contrast, they rated themselves lowest on “Adaptable, innovative, and safety-focused leader in autonomous maritime operations.” The results show that, although the subjects in question have gained basic knowledge and some practical skills in operating, diagnosing, and monitoring automated maritime systems, their level of skills can be restricted compared to those with direct onboard experience. These students are likely to have gained their skills in classroom instruction, simulation training, and theoretical studies, which can efficiently transfer basic cognitive and functional skills, such as knowledge of sensors, controllers, and automation processes, alarm response, and basic troubleshooting (Belabyad *et al.*, 2025) [4]. Nevertheless, the respondents' moderate level of skills implies that they may not yet have reached the depth of shipboard practical judgment, situational sense, or sophisticated troubleshooting one would anticipate after significant hands-on experience with operational shipboard equipment and complex scenario-based operations (Belabyad *et al.*, 2025) [4].

Table 4: Level of Skills of Marine Engineering Students in Operations Related to Autonomous Ships

S. No	Items	With OBT			Without OBT		
		Mean	SD	Int	Mean	SD	Int
1	Skill in sustainable, automated, and emergency-ready maritime operations	3.89	.60	Proficient	3.35	.82	Moderately Proficient
2	Adaptable, innovative, and safety-focused leader in autonomous maritime operations	4.05	.58	Proficient	3.61	.78	Proficient
3	Skill in automated ship systems, diagnostics, and safety monitoring	3.86	.66	Proficient	3.30	.85	Moderately Proficient
4	Ensuring safety, efficiency, and maintenance of digital maritime systems	3.95	.65	Proficient	3.39	.82	Moderately Proficient
5	Proficiency in IT, data analysis, and digital operations	3.78	.77	Proficient	3.32	.92	Moderately Proficient
	Total	3.91	.58	Proficient	3.39	.77	Moderately Proficient

Note: 4.20 – 5.00 Highly Proficient, 3.40 – 4.19 Proficient, 2.60 – 3.39 Moderately Proficient, 1.80 – 2.59 Less Proficient, 1.00 – 1.79 Not Proficient

The overall mean for students with OBT was 3.91 (SD=.58), interpreted as proficient. The result shows that marine engineering students with OBT have gained higher-level technical and operational skills needed in the new era of maritime autonomy. These students not only possess the

ability to monitor and control automated systems and processes on autonomous ships but also demonstrate the ability to troubleshoot, maintain, and optimize conventional and digital shipboard systems. Their level of proficiency shows the integration of hands-on skills with actual ship

operations and a deep understanding of new technologies like sensor integration, data analytics, and remote monitoring, which are needed in autonomous ship management (Campos *et al.*, 2024; Sharma & Kim, 2022) [7, 32].

On the other hand, for students without OBT, the overall mean was 3.39 (SD=.77), interpreted as moderately proficient. The finding suggests that even though they have attained a basic understanding and technical proficiency via scholarly education and simulation-based training, they might not yet have the all-embracing, practical experience offered by actual shipboard operations. The mid-level proficiency hints that they can execute tasks pertaining to autonomous ship systems but might not yet fully have the subtle decision-making skills, situational awareness, and operational flexibility that generally evolve with in-depth practical exposure. With the sea industry moving towards more automation, educational institutions must focus on incorporating new technologies and simulation tools into the curriculum to equip students with this new field (Emad & Ghosh, 2023 [10]; International Maritime Organization, 2021). Nonetheless, findings show that although theoretical learning and simulations are beneficial, they cannot fully substitute the experiential learning needs met during the cadets' on-board training, particularly in mastering soft skills and pragmatic problem-solving skills needed for operating complex, autonomous maritime operations. Thus, students' moderate proficiency in the absence of OBT indicates an encouraging but insufficient preparedness to meet the requirements of fully autonomous shipping systems.

Table 5 shows the attitudes of four groups --- BS Marine Engineering (Marine Engineering) students with On-Board Training (OBT), students without OBT, Marine Engineering instructors, and marine engineers --- towards ship automation. According to the mean range and verbal description scale, all groups fall within the "Optimistic"

category (mean range 3.40–4.19), indicating a generally positive outlook on automation's benefits while possibly retaining some reservations.

Students with OBT have an overall mean of 4.00, placing them near the upper end of the optimistic range and close to being enthusiastic. This suggests they highly support ship automation, appreciating its role in enhancing safety, efficiency, and working conditions. Their practical exposure likely boosts their confidence and eagerness to embrace automation, viewing it as a significant advancement in maritime operations.

Students without OBT, with an overall mean of 3.57, also fall solidly in the optimistic range but at a lower level than those with OBT. This indicates they recognize the benefits of automation and are generally positive but may have more reservations or less certainty about its practical implications, possibly due to limited hands-on experience. Marine Engineering instructors and marine engineers have overall means of 3.74 and 3.82, respectively, within the optimistic range. Their attitudes reflect a balanced appreciation of automation's advantages, such as improved safety and operational ease, while potentially acknowledging challenges in implementation or adaptation. Marine engineers show slightly more optimism in areas like navigation precision and environmental impact, likely influenced by real-world operational experience.

Overall, the results demonstrate a broadly optimistic attitude toward ship automation across all groups, with practical experience (as seen in students with OBT and marine engineers) correlating with higher optimism. None of the groups fall into neutral, skeptical, or resistant categories, indicating general acceptance and positive anticipation of automation's role in modern maritime operations. This optimism suggests readiness to adapt to technological advancements, though some groups may still seek reassurance or further knowledge to embrace these changes fully.

Table 5: Predominant Attitude of BS Marine Engineering Students, Marine Engineering Instructors, and Marine Engineers towards Ship Automation

S. No	Items	Students With OBT			Students Without OBT			Mar E Instructors			Marine Engineers		
		Mean	SD	Int	Mean	SD	Int	Mean	SD	Int	Mean	SD	Int
1	Autonomous ships contribute to the work conditions of seafarers.	4.09	.77	O	3.57	.85	O	3.65	.59	O	3.80	.93	O
2	Automating ships has the potential to improve safety and reduce human error significantly, which is a major cause of accidents at sea.	4.05	.80	O	3.66	.82	O	3.85	.81	O	3.88	.90	O
3	Automation brings new technologies with more potential benefits than negative effects.	4.05	.76	O	3.56	.83	O	3.80	.83	O	3.80	.83	O
4	Seafaring jobs can be fully automated, even though they are complex and require significant cognitive effort, especially in operations and management.	3.91	.86	O	3.53	.84	O	3.25	.91	O	3.40	.95	O
5	Automating ships has the potential to significantly improve safety and reduce human error, which is a major cause of accidents at sea.	3.98	.80	O	3.54	.82	O	3.80	.70	O	3.78	1.04	O
6	Human-operated systems on board can be more reliable with automated and computer-controlled technology.	4.00	.81	O	3.56	.82	O	3.90	.45	O	3.96	.90	O
7	Ship automation can aid seafarers in their daily tasks, making their jobs easier.	4.08	.76	O	3.60	.82	O	3.90	.45	O	3.84	1.02	O
8	Ship automation can improve the quality of work at sea, reducing perennial problems such as fatigue, excessive paperwork, and boredom.	4.00	.73	O	3.60	.84	O	3.90	.55	O	3.82	.85	O
9	Autonomous technology can take over repetitive and dangerous tasks, protecting seafarers from harm and improving working conditions.	3.95	.76	O	3.56	.87	O	3.75	.64	O	3.80	1.05	O
10	Automated ships can navigate more precisely, optimizing routes and fuel consumption for reduced environmental impact.	3.94	.79	O	3.54	.88	O	3.60	.75	O	4.10	.81	O
	Overall	4.00	.66	O	3.57	.74	O	3.74	.47	O	3.82	.74	O

Note: 4.20 – 5.00 Enthusiastic, 3.40 – 4.19 Optimistic, 2.60 – 3.39 Neutral, 1.80 – 2.59 Skeptical, 1.00 – 1.79 Resistant

The optimistic attitude of BS Marine Engineering students with OBT indicates that their field exposure has provided them with an understanding of the possible advantages of automation in the shipping sector. Such students likely understand that autonomous technology can alleviate some of the most challenging aspects of seafaring, including extended periods away from home, physically demanding labor, and exposure to hazardous environments. Automation can reallocate seafarers' duties from conventional hands-on work to more specialized, technology-oriented tasks, such as remote surveillance and system operation, which can increase work-life balance, minimize fatigue, and optimize overall safety and well-being (International Transport Workers' Federation, 2023; Maritime Fairtrade, 2025 ^[23]).

On the other hand, marine engineering students without OBT were optimistic that ship automation can improve the quality of work at sea, reducing perennial problems such as fatigue, excessive paperwork, and boredom, and that it can aid seafarers in their daily tasks, making their jobs easier. The result suggests their optimistic view of the transformative potential of automation in marine operations. These students appreciate that automation can relieve seafarers of repetitive and time-consuming work such as paperwork and routine monitoring, which used to cause fatigue and boredom (Mr. Marine, 2024) ^[25]. Automated systems streamline processes, enhance operational efficiency, and reduce human error, allowing crew members to focus on more complex and engaging responsibilities (Apiworx, 2023) ^[2]. The optimistic attitude of Marine Engineering instructors suggests that marine engineering lecturers are identifying the change potential of automation technology in the maritime industry. Automation is increasingly incorporated into ship operations via systems that manage navigation, monitoring, maintenance, and administration. Such technology can significantly decrease the amount of manual labor needed by seafarers to enable them to concentrate on more complex decision-making and supervisory work rather than repetitive or strenuous work (Nautilus International, 2023 ^[27]; Sedna, 2023). Moreover, by streamlining normal procedures, vessels can reduce human errors, improve safety, and maximize operating efficiency, thereby addressing long-standing issues in maritime work such as fatigue and excessive documentation (Economics Online, 2023) ^[9].

Moreover, the Marine engineers were optimistic that automated ships could navigate more precisely, optimizing routes and fuel consumption for reduced environmental impact. The result reflects the marine engineers' confidence in the sophisticated technologies powering contemporary ship automation. Automated navigation systems use accurate GPS, satellite communication, and real-time data analysis to allow ships to navigate along optimized routes more accurately than manual navigation techniques. This level of accuracy enables ships to make fewer detours, reduce sea time, and choose safer and more fuel-efficient routes, directly lowering fuel usage and greenhouse gas emissions (Williams, 2024) ^[35]. Additionally, they can process vast quantities of navigational and environmental data using artificial intelligence and machine learning, dynamically adjusting routes to incorporate weather, currents, and traffic, which contributes to increased operational efficiency and environmental performance (Maritime Fairtrade, 2025; Nautilus International, 2023) ^[23, 27].

Table 6 presents a comparative analysis of the knowledge levels of marine engineering students with and without Onboard Training (OBT) regarding the operation of autonomous ships. The data includes the number of students (N), mean knowledge scores, standard deviations (SD), t-test statistics, degrees of freedom (df), and p-value to determine the significance of the difference between the two groups.

The results show that students with OBT (N = 65) have a higher mean knowledge score of 4.01 (SD = 0.52), indicating a strong understanding of autonomous ship operations. In contrast, students without OBT (N = 229) have a lower mean score of 3.46 (SD = 0.76), reflecting a comparatively lesser level of knowledge. The t-test value of 6.70 with a p-value of .000 (less than the 0.05 significance level) confirms that this difference in knowledge between the two groups is statistically significant.

This significant difference suggests that Onboard Training plays a critical role in enhancing marine engineering students' knowledge about autonomous ships (Phanphichit & Bartusevičienė, 2024) ^[29]. It enables students studying marine engineering to apply classroom theory to real-world ship conditions, leading to a deeper comprehension of the practical operation of autonomous systems (Hwang *et al.*, 2022) ^[14]. The practical experience gained through OBT likely deepens students' understanding, making theoretical concepts more tangible and relevant. Therefore, incorporating or expanding onboard training in marine engineering curricula could be highly beneficial in better preparing students for the evolving demands of autonomous ship operations.

Table 6: Difference in the Knowledge of Marine Engineering Students with or without Onboard Training

Student	Mean	t	df	p value
With OBT	4.01	6.70*	150.52	.000*
Without OBT	3.46			

*p<0.05 Significant

Onboard training exposes students to real-world situations, technical equipment, and operational issues that cannot be simulated in the classroom or through simulations alone. This hands-on training enhances their knowledge of ship operation, system integration, navigation technology, and emergency procedures, which are critical in dealing with autonomous vessels. Without OBT, students may have book knowledge but lack the context-based understanding necessary to make effective decisions and manage systems in dynamic, real-world sea conditions. Current research highlights that hands-on experience remains essential in learning the intricacies of new maritime technologies, such as autonomous systems, thereby narrowing the wide knowledge gap between OBT and non-OBT students (International Maritime Organization, 2021; Meštrović *et al.*, 2024 ^[24]).

Table 7 compares the skill levels of marine engineering students with and without Onboard Training (OBT) in relation to the operation of autonomous ships. The table provides the number of students (N), mean skill scores, standard deviations (SD), t-test value, degrees of freedom (df), and p-value to assess the significance of differences between the two groups. Students with OBT (N = 65) have a higher mean skill score of 3.91 (SD = 0.58), indicating a relatively strong proficiency in the skills necessary for

autonomous ship operations. Conversely, students without OBT (N = 229) have a lower mean score of 3.39 (SD = 0.80), showing a comparatively weaker skill set. The t-test value of 5.86 with a p-value of .000 (which is below the 0.05 threshold) demonstrates that this difference in skills between the two groups is statistically significant.

This significant difference highlights the important role that onboard training plays in developing practical skills among marine engineering students. The hands-on experience gained through OBT likely enhances students' ability to apply theoretical knowledge effectively in real-world autonomous ship operations (Dewan *et al.*, 2023). OBT equips with practical skills and underpins theoretical learning, leading to overall competence in the maritime sector. OBT enables students to juxtapose theory and practice and comprehend and put knowledge into practice in real life (Phanphichit & Bartusevičienė, 2024) ^[29]. These findings support the inclusion or expansion of onboard training programs within marine engineering education to better equip students with the skills demanded by modern maritime technologies.

Table 7: Difference in the Skills of Marine Engineering Students with or without onboard training

Student	Mean	t	df	p value
With OBT	3.91	5.86*	135.02	.000*
Without OBT	3.39			

*p<0.05 Significant

In onboard training, students receive hands-on experience in operating vessels, managing systems, and decision-making during the operation of conventional and autonomous ships. Practical experience also increases their capacity to translate theoretical knowledge into practice, work with advanced systems, and adapt efficiently to changing maritime environments, all of which are crucial for the safe and efficient operation of autonomous ships. Lynch *et al.* (2024) explain that Knowledge of autonomous systems, like AI, sensors, and navigators, is useful theoretically. However, real-world experience enables one to observe how these technologies function under real-time conditions. Such practical experience enables them to realize the systems' shortcomings, how they could fail, and how to use them best. Further, practical experience becomes essential in refining the skill for coping with the changes. One needs to learn these things: how weather patterns, sea streams, and other ships can interfere with autonomous shipping, and what one must change in response to that (Anderson, 2024). Without this experience, students may possess good theoretical knowledge but lack the operational skills and situational awareness required for effective autonomous ship management (International Maritime Organization, 2021; Meštrović *et al.*, 2024 ^[24]).

Table 8 compares the attitudes of marine engineering students with and without Onboard Training (OBT) toward ship automation. The data includes the number of students (N), mean attitude scores, standard deviations (SD), t-test value, degrees of freedom (df), and p-value to determine if the difference between the two groups is statistically significant.

Students with OBT (N = 65) have a higher mean attitude score of 4.00 (SD = 0.66), indicating a generally optimistic and positive attitude toward ship automation. In contrast, students without OBT (N = 229) have a lower mean score of

3.57 (SD = 0.74), reflecting a less positive but still optimistic attitude. The t-test value of 4.28 with a p-value of .000 (less than the 0.05 significance level) confirms that the difference in attitude between the two groups is statistically significant.

This significant difference suggests that onboard training has a positive influence on students' attitudes toward ship automation. The practical exposure and firsthand experience gained during OBT likely enhance students' confidence and acceptance of automated maritime technologies. Therefore, incorporating onboard training into marine engineering programs not only improves knowledge and skills but also fosters a more favorable and proactive mindset toward technological advancements in the maritime industry.

Table 8: Difference in the Attitude of Marine Engineering Students with or without Onboard Training

Student	Mean	t	df	p value
With OBT	4.00	4.28*	292	.000*
Without OBT	3.57			

*p<0.05 Significant

Moreover, the finding suggests that experience has a significant influence on students' attitudes and receptiveness to technological innovation in shipping. Research indicates that students often lack knowledge of autonomous shipping and commonly perceive automation as both a potential safety enhancement and a threat to conventional seafaring careers (Nasur & Bogusławski, 2020) ^[26]. However, those with OBT will likely have gained a more sophisticated understanding, based on actual experience of ship operations, to enable a greater appreciation of both the advantages and disadvantages of automation. (Hwang *et al.*, 2022) ^[14]. Further, through on-board training, cadets will determine an area of strength or weakness of a particular seafarer, impart to him the essential on-board know-how and competence development, and present him with a "benchmark" matrix of capabilities that will aid in his appraisal at the next level for a promotion (Mariner Skills, 2021). Students lacking OBT might be more reliant on theory or hearsay, tending perhaps to be less confident in their preparedness for autonomous technologies and more uncertain or concerned about the impact on future employment (Bogusławski *et al.*, 2022) ^[5]. This discrepancy highlights the need to incorporate practical training and thorough coverage of automation-related subjects into maritime education, thereby adequately equipping all students for the emerging needs of autonomous ship operations (Meštrović *et al.*, 2024) ^[24].

Table 9 presents the correlation analysis between Knowledge, Skills, and Attitude of marine engineering students with and without onboard training. The table shows the sample size (N), p-value, and the interpretation of the significance of the correlations.

The reported p-value of .000 (which is less than the 0.05 significance level) indicates that there is a statistically significant correlation among the variables --- knowledge, skills, and attitude-across the combined group of 294 students. This result implies that these three factors are meaningfully related. In other words, students with higher knowledge about autonomous ship operations also tend to have better skills and more positive attitudes toward the technology. It is because a good foundation of autonomous ship operations facilitates the learning of more sophisticated

skills like troubleshooting, system diagnostics, and interaction with automation systems (Maghoromi, 2023) [22]. Moreover, more knowledgeable students are more likely to have a positive disposition towards autonomous technologies since they can see the potential benefits and are better equipped to incorporate them into their practice (Bogusławski *et al.*, 2022) [5]. This finding underscores the interconnected nature of cognitive understanding, practical ability, and mindset in the context of marine engineering education, especially regarding autonomous ship operation. The significance across students with and without onboard training suggests that, regardless of training status, these three domains influence each other. This also implies that enhancing one area (e.g., knowledge through onboard training) could positively impact skills and attitudes. The significant correlation among knowledge, skills, and attitude highlights the importance of a holistic educational approach that simultaneously develops cognitive understanding, practical competencies, and positive perceptions. This reinforces the value of onboard training as a means to enhance knowledge and skills, and foster a constructive attitude toward emerging maritime technologies, such as autonomous ships.

Table 9: Correlation among Knowledge, Skills, and Attitude of Marine Engineering Students with and without Onboard Training

Model		Knowledge	Skills	Attitude
Knowledge	Pearson's Correlation	1	.894**	.717**
	Sig. (2-tailed)		.000	.000
Skills	Pearson's Correlation	.894**	1	.729**
	Sig. (2-tailed)	.000		.000
Attitude	Pearson's Correlation	.717**	.729**	1
	Sig. (2-tailed)	.000	.000	

*Correlation is significant at the 0.01 level (2-tailed)

Knowledge forms the theoretical base and system understanding; skills bring the knowledge to practical technical, operational proficiency; and attitude conditions how students face challenges, respond to new technology, and ensure safety and professionalism in the maritime context. Whether or not onboard training is provided has a determining effect on enhancing or diminishing such relationships. Students who receive onboard training are more inclined to integrate skills and knowledge appropriately, form good attitudes toward the adoption of technology, and be more adaptable and safety-conscious in real-life situations. As explained by Kamis *et al.* (2024), knowledge received from training enhances one's attitude, thus leading to improved behavior. Furthermore, as it fosters an engaging learning environment for knowledge generation, collaboration opportunities, and active engagement among trainees, this information helps cultivate a favorable attitude toward developing technologies (Maghoromi, 2023) [22]. Accordingly, this study determined the effects of BT on seafarers' shipboard safety.

On the other hand, untrained individuals will find it challenging to bridge the gaps between theory and practice, leading to decreased confidence and readiness for autonomous ship operations. This factor serves to emphasize that maritime education programs must comprehensively address KSA development, particularly as the sector moves towards autonomous and digitally operated operations (Ghosh & Emad, 2024 [13]; Subramanyam & Dhankher, 2022; Meštrović *et al.*, 2024 [24]).

Table 10 presents the perspectives of Marine Engineering (Marine Engineering) instructors on how to integrate the skillsets required for operating autonomous ships into the Bachelor of Science in Marine Engineering (BS Marine Engineering) curriculum. Among the 20 instructors surveyed, half (50%) advocate teaching these skills as a separate, specialized course in the final academic year, emphasizing the importance of a dedicated, focused approach to mastering autonomous ship operations. This approach aligns with the growing complexity and specialized knowledge required in the field, ensuring students gain comprehensive and concentrated training before graduation.

Meanwhile, 35% of instructors prefer integrating these skills as additional topics within existing courses, suggesting a more incremental approach that embeds autonomy-related concepts throughout the curriculum. This method may facilitate gradual exposure without overhauling the entire program structure. A smaller portion (10%) supports providing this training after academic requirements but before shipboard training, which implies a transitional, practical preparation phase. Only 5% believe that training should be left to shipping companies rather than included in academic programs, indicating strong instructor consensus that autonomous ship operation skills are essential to formal marine engineering education. Overall, these results highlight the recognized need for curriculum adaptation to prepare students effectively for the evolving demands of autonomous maritime technology.

Table 10: Integrating the Skillsets in Operating Autonomous Ships into the BS Marine Engineering Curriculum from the Perspective of Marine Engineering Instructors

S. No	Items	Total	
		Frequency	Percent
1	Teaching them as a separate package of skills in one specialized course in the BS Marine Engineering students' final academic year.	10	50
2	Integrating them as additional topics within existing courses/subjects	7	35
3	Adding them as a required set of training after they have completed their academic requirements, before their shipboard training	2	10
4	Leaving it to the shipping companies that subscribe to the automation of ships (not to be given as a requirement to Marine Engineering students during their academic training)	1	5
	Total	20	100

As shown on the table, the majority of the marine engineering instructors identified "Teaching them as a separate package of skills in one specialized course in the BS Marine Engineering students' final academic year" to be integrated in the BS Marine Engineering curriculum. The results reveal the marine engineering educators' acknowledgment of the unique and sophisticated skills required to operate Maritime Autonomous Surface Ships (MASS), noting that these skills are significantly different from those demanded by traditional ships. This methodology acknowledges that developing autonomous ships introduces new challenges and demands, particularly in areas such as digital competence, systems engineering,

remote control, cybersecurity, and advanced human-machine interaction. Supporting the implementation of a stand-alone specialist course, faculty members emphasize the need to address these emerging skill sets systematically. This approach ensures that the next generation of marine engineers not only master classical maritime knowledge but also acquire the technical, operational, and management expertise essential for autonomous systems. This is consonant with newer studies emphasizing the need for institutions of maritime education and training (MET) to revise curricula in line with changing industry expectations and regulatory developments, including those being influenced by the International Maritime Organization (IMO) (Belabyad *et al.*, 2025; Campos *et al.*, 2024) ^[4, 7].

The shift to integrate these skills into a concentrated course in the last year of study acknowledges that mastery of autonomous ship technologies requires a hybrid model, balancing core seafaring skills with new digital and analytical skills. This approach is designed to equip graduates for the challenges of a rapidly evolving maritime environment, enabling workforce flexibility and the safe and efficient adoption of autonomous shipping technologies.

Table 11 reflects the perspectives of BS Marine Engineering (BS Marine Engineering) students on how the skillsets needed to operate autonomous ships should be integrated into their curriculum. A significant majority --- 75% of the 294 students surveyed --- prefer that these skills be taught as a specialized course in their final academic year. This strong preference suggests that students recognize the complexity and importance of autonomous ship operations and believe that dedicated, focused instruction is necessary to acquire the relevant competencies effectively.

Meanwhile, 19% of students support integrating these skills as additional topics within existing courses, indicating some openness to a more gradual or embedded approach to learning about autonomous systems. Only a small minority (6%) believe that training in autonomous ship operations should be left to shipping companies after graduation, rather than being a formal part of their academic education. This distribution shows a clear student consensus that maritime education should proactively prepare them for the evolving demands of autonomous shipping. It aligns with broader industry trends emphasizing the need for updated curricula to address emerging technologies and operational challenges in maritime autonomous surface ships.

Table 11: Integrating the Skillsets in Operating Autonomous Ships into the BS Marine Engineering Curriculum from the Perspective of BS Marine Engineering Students

S. No	Items	Total	
		Frequency	Percent
1	Teaching them as a separate package of skills in one specialized course in the BS Marine Engineering students' final academic year.	221	75
2	Integrating them as additional topics within existing courses/subjects	55	19
3	Leaving it to the shipping companies that subscribe to the automation of ships (not to be given as a requirement to Marine Engineering students during their academic training)	18	6
	Total	294	100

The result shows high awareness among students that the skills necessary for independent ship operation differ from those for conventional maritime and need specific, specialized education. This preference demonstrates an appreciation that MASS operation necessitates a combination of cutting-edge technical, digital, operational, and managerial capabilities, such as automation engineering, data analysis, remote operations, systems integration, and software management beyond the standard curriculum (National Maritime Polytechnic, 2023).

In addition, studies show that autonomous ship operators in the future will need an integrated skill set encompassing information and communication technology (ICT) skills, machinery operation skills, and troubleshooting capabilities for sophisticated systems. A qualitative study in the 'WMU Journal of Maritime Affairs' highlights the need for specialized training to acquire these skills, indicating that conventional maritime education might not adequately address the complexity of autonomous ship operations (Gholam & Ghosh, 2023) ^[12].

Table 12 reveals that most respondents (40%) prefer incorporating autonomous ship operation skills as mandatory training after completing academic requirements but before shipboard training, emphasizing practical preparation before real-world application. A significant portion (34%) favors teaching these skills as a separate, specialized course in the final academic year, highlighting interest in a dedicated academic focus. Fewer respondents (14%) support integrating the skills into existing courses as additional topics. In comparison, the smallest group (12%) believes training should be left to shipping companies, suggesting these skills need not be part of formal academic programs.

Table 12: Integrating the Skillsets in Operating Autonomous Ships into BS Marine Engineering Curriculum (Marine Engineers)

S. No	Items	Total	
		Frequency	Percent
1	Adding them as a required set of training after they have completed their academic requirements, before their shipboard training	20	40
2	Teaching them as a separate package of skills in one specialized course in the BS Marine Engineering students' final academic year.	17	34
3	Integrating them as additional topics within existing courses/subjects	7	14
4	Leaving it to the shipping companies that subscribe to the automation of ships (not to be given as a requirement to Marine Engineering students during their academic training)	6	12
	Total	50	100

The result implies that there is a wide agreement that practical, hands-on training must be officially incorporated as a compulsory link between theoretical studies and real onboard experience. The strategy addresses the need for students to integrate and apply their academic learning in a controlled workshop environment, where they can develop key technical, safety, and operational competencies before being exposed to the challenges of actual shipboard responsibilities. Such a requirement guarantees that

graduates are not only academically qualified but also practically capable and confident in operating ship systems, machinery, and emergency procedures, meeting international standards such as the STCW Convention and industry best practices (Warsash Maritime, 2025; Allsopp *et al.*, 2006 as cited in Georgiou *et al.*, 2025 ^[11]).

The most common initiative implemented by shipping companies to prepare their engine officers and crew for the eventual adaptation to autonomous ships was “*Conducting orientation on updates/latest equipment used on board the company’s vessels related to Autonomous Surface Ships (MASS)*.” This result shows active readiness for work during a speedy transformation of technologies. This strategy ensures that engine officers and staff are consistently trained on the latest technologies, running procedures, and safety practices used in autonomous and remotely operated machines. By giving precedence to such orientations, companies facilitate filling the knowledge gap generated by the rapid convergence of digitalization and automation in shipping, allowing personnel to adjust to new responsibilities and roles with assurance and proficiency.

Table 13: Initiatives Implemented by Shipping Companies to Prepare Their Engine Officers and Crew for the Eventual Adaptation to Autonomous Ships

S. No	Items	Total	
		Frequency	Percent
1	Conducting orientation on updates/latest equipment used on board the company’s vessels related to Autonomous Surface Ships (MASS)	16	80
2	Providing training aimed at improving the officers and crews’ personal, organizational, and managerial skills, such as creativity, entrepreneurial thinking, problem solving, conflict	2	10
3	Advanced training program or specific crew training necessary to increase their knowledge, skills, and understanding to work in a more digitalized shipping environment solving, decision making, analytical skills, research skills, efficiency orientation, ability to take initial actions in emergency situations, along with the leadership and teamwork skills	1	5
4	Reviewing policies related to the implementation of ship automation, e.g., IMO Regulations	1	5
	Total	20	100

The proposed Technological Skills Enhancement Plan aims to enhance the BS Marine Engineering curriculum and the competence of BS Marine Engineering students.

The maritime industry is rapidly evolving with advances in vessel automation, sustainable propulsion systems, and stricter international regulations. To ensure that graduates of the BS Marine Engineering (BSMarE) program remain globally competitive and fully compliant with the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), it is essential to integrate a specialized course package into the curriculum.

The result of the study indicated that Marine Engineering Instructors identified that essential skills needed to operate an autonomous ship include the ability to make use of new working methods, IT and digital skills, managing

automation failure with onshore support, and emission monitoring and documentation, which coincide with the skills that garnered the lowest scores as per students’ assessment.

To address this gap, a specialized course package is proposed as an elective in the final academic year of the BS Marine Engineering curriculum to enhance the competencies of Marine Engineering students in technologies and operations related to Autonomous Ships.

Results and Discussions

The results/findings of the study summarized below:

- Overall, the marine engineering instructors and marine engineering students, both with and without onboard training, were “highly knowledgeable,” which means they possess a comprehensive and in-depth understanding of the requirements for operating autonomous ships, and they are highly familiar with the core technologies involved in operating autonomous ships (Aboul-Dahab, 2021).
- The data on the skills essential for operating autonomous ships of marine engineering instructor indicates that the following skills are vital in such operations: ability to make use of new working methods, adopting the safety mindset of the tanker/gas fleet when working with new fuel types, ability to perform safe vessel and equipment maintenance with more hazardous fuels on board, emission monitoring and documentation, IT and digital skills and managing automation failure with onshore support.
- The marine engineers, marine engineering instructors, and marine engineering students are optimistic about ship automation. It means that they recognize the benefits of automation, are generally positive about its impact, and appreciate the improvements in efficiency and safety that automation can bring but may have some reservations or concerns about its implementation. They are also open to embracing new technologies and are willing to adapt but seek reassurance regarding the changes (Chan *et al.*, 2023).
- Students with onboard training have considerably higher and broader knowledge, a higher skills level, and a more positive attitude towards ship automation than students without onboard training. This shows that actual experience in the field boosts the knowledge and skills of the students, as well as develops a positive attitude towards ship automation.
- There is a strong correlation between marine engineering students’ knowledge, abilities, and attitudes about ship automation. A dynamic relationship exists between students’ knowledge, abilities, and perceptions of automation in marine environments, as each component appears to impact and support the others.
- For the integration of skills into the marine engineering curriculum, the data gathered shows that the majority of the marine engineering students and instructors prefer that those skills will be taught as a separate package of skills in one specialized course in the BS Marine Engineering students’ final academic year while marine engineers prefer both teaching them as a separate package of skills in one specialized course in the BS Marine Engineering students’ final academic year and adding them as a required set of training after they have completed their academic requirements before their

shipboard training.

7. The findings indicate that shipping companies are already offering orientations on the newest technology and equipment utilized on their ships, particularly concerning Maritime Autonomous Surface Ships (MASS). This program is a proactive measure to have its marine engineers ready for the operation of autonomous ships in the future. These businesses aim to ensure a seamless transition to autonomous vessel operations by familiarizing crew members with cutting-edge systems and automation technologies.
8. The Proposed Technological Skills Development Plan for the BS Marine Engineering program strongly emphasizes adding a two-semester modular course for the students' final year.

Conclusion

Marine engineering instructors are generally knowledgeable and effective in teaching students about the operation of autonomous ships. However, there remains a need to further enhance their understanding in areas such as artificial intelligence (AI), automation, and the Internet of Things (IoT) as applied to marine engineering systems. Strengthening their expertise in these emerging technologies will enable them to provide more relevant and up-to-date instruction. Meanwhile, marine engineers have demonstrated readiness to operate autonomous vessels, indicating a solid foundation of skills and competencies. Continued professional development for instructors will help ensure that future engineers remain prepared for advanced maritime operations.

Marine engineering instructors must have a broad range of abilities that meet safety and technology requirements to operate autonomous ships, such as adaptability to new working methods, a strong safety mindset, particularly when handling hazardous fuels, competence in maintaining vessels and equipment, proficiency in monitoring and documenting emissions, strong IT and digital capabilities, and the capacity to handle automation failures in conjunction with onshore support. In the dynamic maritime sector, these skills are necessary to guarantee safe, effective, and ecologically conscious operations.

The findings indicate that students, instructors, and marine engineers have a generally positive outlook on ship automation. They understand and value automation's potential advantages, especially in improving productivity and security. They present a balanced viewpoint that values innovation and careful implementation, as they are willing to embrace new technology and adjust to change, while also indicating a need for assurance and assistance during the transition.

The students' knowledge, abilities, and attitudes toward ship automation have significantly improved as a result of their onboard training experience. Their comprehension of automated systems has improved through this practical experience, and they now feel more confident in utilizing these technologies. Additionally, it helped them develop a more optimistic and flexible outlook, which equipped them to work efficiently with contemporary maritime technologies. All things considered, the training was very important in helping them become more competent and prepared for automation in the shipping sector.

The attitudes, abilities, and knowledge of marine engineering students about ship automation are closely

related. They become more adept at automation and more receptive to its use as their comprehension grows. According to this correlation, increased education and hands-on automation experience have a beneficial impact on competence and mindset, which helps people become more equipped to meet the changing needs of the maritime sector.

The study reveals that marine engineering instructors, students, and engineers prefer skills related to operating autonomous ships to be taught as a distinct set within a specialized course during the final academic year of the BS Marine Engineering program. This approach ensures focused training and better preparation for handling advanced maritime technologies.

Shipping companies are aggressively training their marine engineers through seminars and orientations as they become more conscious of the upcoming automation of ship operations. To ensure that engineers are prepared to shift to increasingly automated maritime systems, these training courses concentrate on the technologies and equipment utilized on their boats, particularly those associated with Maritime Autonomous Surface Ships (MASS).

Recommendations

In connection with the obtained findings and given conclusions, the following were recommended:

For Maritime Higher Education Institutions

Autonomous ship technology may be incorporated into maritime schools' curricula to better train cadets for the changing shipping sector. One example is offering specialized courses in cybersecurity, sensor systems, artificial intelligence, and remote vessel operations. Students will be offered real-time simulations and practical experience through partnerships with shipping businesses and technology developers. For faculty to properly present new material, they should also receive upskilling. Modern training facilities that model independent operations and promote interdisciplinary learning are also essential investments for educational institutions. To encourage responsible innovation, regulatory frameworks and ethical issues pertaining to unmanned ships should be highlighted. In a world business that is evolving quickly, maritime institutions can guarantee that their graduates are competitive and capable of managing both conventional and next-generation boats by adjusting early.

For Maritime Training Centers

In order to prepare for the transition to autonomous ship operations, maritime training facilities may opt to upgrade their infrastructure and training curricula. Modules on cybersecurity, data analytics, automation systems, and remote navigation must be included to give sailors the tools they need for future positions. Simulators should be improved to recreate situations with crew-assisted and autonomous vessels. Collaborations with research institutes and maritime technology companies will guarantee access to the newest developments and industry best practices. Developing critical thinking and decision-making abilities in intricate, technologically advanced settings should be another priority for training facilities. Throughout the transition, regular training and certification programs for existing marine professionals will aid in closing the gap. With the marine industry becoming more automated, these steps will guarantee that maritime workers stay competent and relevant.

For Shipping Companies

By investing in workforce training, digital infrastructure, and research, shipping businesses may start making strategic preparations for integrating autonomous ships. Collaborating with technology suppliers and regulatory agencies can ensure a smooth adoption and adherence to evolving international standards. To ensure operational safety and efficiency, companies should upskill current crew members in areas like as cybersecurity, AI-assisted navigation, and remote vessel monitoring. Data and insights can be obtained from pilot projects and hybrid operations that gradually incorporate autonomous elements. Additionally, shipping companies need to review and update maintenance plans, emergency response plans, and risk management practices specific to unmanned operations. In the face of revolutionary technological change in the marine sector, shipping businesses can maintain their competitiveness and resilience by embracing innovation and cultivating a culture of constant learning.

For BS Marine Engineering Students

Students studying marine engineering may broaden their expertise beyond standard engineering courses to include automation, artificial intelligence, robotics, and advanced sensor technology, thereby preparing for the shift to autonomous ships proactively. Maintaining and debugging autonomous vessels will require understanding how mechanical and digital control systems interact. Students should gain hands-on experience with smart engine systems, remote diagnostics, and cybersecurity protocols to manage shipboard technology effectively. Their preparedness can be improved by participating in multidisciplinary projects and autonomous system simulations. It is also critical to keep up with new standards and international laws pertaining to unmanned ship operations. Marine engineering students may ensure they continue to be useful assets in the increasingly automated and digitalized maritime industry by developing technical skills and adaptability.

For Future Researchers

Future studies should focus on developing new technologies and addressing existing constraints to enhance the safe and effective operation of autonomous ships. Artificial intelligence, sensor fusion, machine learning for navigation and decision-making, and strong cybersecurity systems are priority topics. Researchers should also study models of human-machine interaction to guarantee seamless supervision and intervention when required. Research can be better aligned with practical requirements and changing standards by collaborating with academic institutions, regulatory bodies, and maritime companies. Studying the effects of automation on the environment, economy, and ethics is also necessary. Testing and validation can also be improved by creating digital twins and scalable simulation environments. Scholars can have a significant impact on the development of autonomous maritime operations in the future by conducting multidisciplinary and innovative research.

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