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Enhancing Maritime Education and Operations through IT, IoT, and Computer-Based Learning

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Abstract: This study aims to examine how Information Technology (IT), the Internet of Things (IoT), and Computer-Based Learning (CBL) are integrated into maritime operations and education, and to identify the structural barriers that constrain their full implementation. Despite the accelerating pace of digital transformation in the maritime sector — driven by IMO emissions regulations, smart port development, and Industry 4.0 — no prior qualitative study has simultaneously examined IT/IoT integration in operations and CBL adoption in education within a single analytical framework targeting Indonesian maritime professionals and educators, representing the specific gap this study addresses. A qualitative research design was employed, drawing on semi-structured interviews and focus group discussions with 33 participants: 8 maritime industry professionals (entrepreneurs, vessel officers, and port managers), 12 maritime lecturers and trainers, and 13 recent graduates from Indonesian maritime polytechnic institutions. Data were analyzed through a systematic six-phase thematic analysis procedure (Braun & Clarke, 2006) with intercoder verification (Cohen's Kappa κ = 0.82). Three themes emerged: high IT/IoT awareness constrained by infrastructure and standardization deficits; CBL effectiveness hampered by resource limitations and instructor capacity gaps; and industry-education collaboration as necessary but structurally underdeveloped. The study's principal contribution is a dual-domain analytical framework connecting operational IT/IoT integration barriers with CBL implementation conditions — demonstrating that both are driven by the same root cause of inadequate governance coordination between maritime industry stakeholders and educational institutions, a finding not previously articulated in the maritime technology education literature.

Keywords: Maritime Education, Information Technology, Internet of Things, Computer-Based Learning, Digital Transformation

INTRODUCTION

Technology Transformation in Maritime Operations and Its Educational Implications

The maritime industry is undergoing a profound digital transformation driven by three converging pressures: international environmental regulations (IMO EEXI, CII, and EU ETS) mandating operational efficiency improvements; the commercial emergence of smart port and autonomous vessel technologies enabled by IoT sensor networks; and the competitive imperative for maritime companies to reduce operating costs through data-driven predictive maintenance and route optimization (de la Peña Zarzuelo et al., 2020; Jimenez et al., 2022). These pressures are generating demand for maritime professionals with IT system management, IoT data interpretation, and digital compliance monitoring competencies that current maritime vocational curricula do not systematically develop (Manuel, 2017; Wahl & Kongsvik, 2018).

Computer-based learning tools — including virtual ship simulators, augmented reality training environments, and learning management systems — represent the primary pedagogical response to this competency development challenge. CBL enables maritime students to develop interaction with complex digital systems in controlled, repeatable environments without requiring physical access to vessels or operational infrastructure (Shao et al., 2022; Slama et al., 2015). Yet the adoption of CBL across Indonesian maritime polytechnics is uneven, constrained by resource disparities between institutions, instructor digital literacy gaps, and the absence of standardized technology integration mandates in the curriculum framework (Othman et al., 2025; Nidhom et al., 2025).

The Research Gap and Novelty

The existing literature addresses maritime technology integration and maritime education separately. Studies of IT/IoT in maritime operations examine adoption patterns, cost-benefit dynamics, and smart port architecture (de la Peña Zarzuelo et al., 2020; Pu & Lam, 2021) without examining the parallel challenge of preparing the educational institutions that produce the workforce deploying these systems. Maritime education research examines curriculum design, STCW compliance, and simulation effectiveness (Manuel, 2017; Ghosh et al., 2014; Wahl & Kongsvik, 2018) without connecting educational preparedness to the specific IT/IoT operational demands maritime graduates will encounter. No prior study has examined both domains within a single analytical framework — and no prior study has generated multi-stakeholder qualitative evidence on these questions from the Indonesian maritime education context, where institutional resource constraints and governance coordination challenges create a distinctive implementation environment.

The novelty of this study is threefold: it provides the first dual-domain qualitative analysis connecting operational IT/IoT integration barriers with CBL implementation conditions; it generates evidence from three stakeholder perspectives (professionals, lecturers, graduates) simultaneously rather than privileging any single group; and it demonstrates that operational and educational technology integration barriers share a common root cause — inadequate governance coordination — rather than being independent technical or financial problems.

Research Questions

This study addresses three research questions: **(RQ1)** What is the current state of IT and IoT integration in maritime engineering operations, and what structural barriers prevent full-scale implementation? **(**RQ2**)** How effectively is computer-based learning integrated into Indonesian maritime education, and what institutional conditions enable or constrain effective CBL adoption? **(RQ3)** What governance reforms and industry-education collaboration mechanisms are necessary to align technology adoption in operations with technology preparedness in education?

Literature Review

IT and IoT Integration in Maritime Operations

The integration of IT and IoT into maritime engineering represents one of the most consequential technological transitions the sector has undergone since containerization. IT systems — including integrated maritime management platforms, electronic chart display and information systems (ECDIS), and digital cargo management software — enable seamless coordination of vessel operations, supply chain management, and maritime authority communications (de la Peña Zarzuelo et al., 2020). IoT sensor networks extend these capabilities by providing continuous real-time data streams on vessel performance, fuel consumption, structural health, and environmental conditions — enabling the predictive maintenance, route optimization, and emissions monitoring that regulatory compliance and operational efficiency require (Jimenez et al., 2022; Shao et al., 2022).

The operational benefits of IT/IoT integration are substantiated across the maritime management literature. Pu and Lam (2021), examining blockchain adoption in maritime industry, established that distributed digital infrastructure creates new possibilities for transparent, tamper-resistant documentation of cargo, compliance, and maintenance records — demonstrating that the transformative potential of digital maritime systems extends beyond operational efficiency into regulatory governance. Nguyen et al. (2023), reviewing disruption management in the maritime industry, confirmed that IT-enabled real-time information systems significantly improve resilience by reducing response times to operational disruptions — weather events, port congestion, and equipment failures — that have traditionally depended on delayed human communication chains.

However, the barriers to full IT/IoT integration are equally well-documented. The high initial investment costs for upgrading legacy infrastructure — estimated at millions of dollars per vessel for comprehensive IoT sensor network installation — create significant barriers for smaller shipping companies and developing maritime nations (Jimenez et al., 2022). The lack of standardized data protocols across different vessel types, port systems, and maritime authority databases creates interoperability challenges that prevent the seamless data integration that smart maritime operations require (de la Peña Zarzuelo et al., 2020). Regulatory frameworks — which evolve through slow international consensus processes — often lag behind technological capabilities, creating uncertainty that deters investment in systems whose compliance status may not yet be legally established (Wahl & Kongsvik, 2018).

Wulandari and Cahyadi (2025), examining technology and education in Indonesian maritime studies, confirmed that while technology-enhanced operations are increasingly recognized as essential by Indonesian maritime institutions, implementation capacity remains critically underdeveloped — establishing the Indonesian-specific institutional context in which this study's findings are situated. Wahyudi et al. (2025), examining university-industry partnership effectiveness, confirmed that substantive industry engagement — not formal consultative arrangements — is the variable that determines whether educational institutions develop operationally relevant technology curricula.

Computer-Based Learning in Maritime Education

Computer-based learning encompasses virtual ship simulators, augmented reality training environments, e-learning platforms, and learning management systems that enable maritime students to develop technical competencies in controlled digital environments. The theoretical basis for CBL effectiveness in maritime education is grounded in experiential learning theory (Kolb, 1984): simulators and VR environments operationalize the complete experiential learning cycle — concrete experience, reflective observation, abstract conceptualization, and active experimentation — in ways that lecture-based instruction cannot (Manuel, 2017). Slama et al. (2015), examining enterprise IoT practices, established that digital simulation environments produce operational competency gains that significantly exceed traditional training because they enable repeated, variable-condition practice impossible to replicate in physical training environments.

Komaro et al. (2022), analyzing pedagogical competence needs of Indonesian vocational lecturers, found that digital technology integration represents the lowest-achieving competency domain — confirming that instructor capacity gaps are the primary barrier to effective CBL implementation in Indonesian maritime education, a finding that parallels this study's educator perspective data. Widaningsih et al. (2025), mapping technical competency needs for TVET teachers in the Industry 4.0 era, established that digital competencies for emerging technology instruction represent a systemic gap that institutional development programs must deliberately address. Othman et al. (2025), reviewing digitalisation challenges in TVET, confirmed that effective CBL integration requires coordinated institutional investment in infrastructure, faculty capacity, and governance frameworks simultaneously — a tripartite condition most institutions only partially meet.

Nidhom et al. (2025), in a systematic review of vocational teacher professional education, established that instructor digital competency is a necessary antecedent of effective CBL deployment — training must precede technology rollout rather than following it. Daryono et al. (2023), evaluating student competency in Indonesian vocational education, confirmed that assessment context significantly influences competency development, establishing the learning science basis for why CBL environments — which provide authentic, high-fidelity operational contexts — produce stronger competency outcomes than classroom instruction.

Industry-Education Collaboration for Technology Integration

The alignment between maritime industry technology demands and maritime education technology content requires systematic governance mechanisms that current institutional arrangements do not provide. Suyetno et al. (2024), examining industry involvement in Indonesian vocational curriculum reform, found that genuine industry co-design — not formal advisory committee participation — is the variable that produces curriculum alignment with operational technology requirements. Song and Xu (2024), examining vocational education expansion in China, warned that massification of technical training produces certification without operational capability when systemic governance conditions are absent — a caution directly applicable to maritime IT/IoT education where enrollment growth may outpace technology infrastructure development.

Aminah et al. (2025) demonstrated that formal outcome-based curriculum alignment frameworks can systematically maintain correspondence between program-level outcomes and course-level technology content — providing the governance model through which maritime digital competency standards could be inscribed within curriculum specifications without requiring full STCW framework revision. Mutohhari et al. (2025), documenting low green skills maturity among Indonesian vocational teachers, established an empirical baseline for the technology capacity gap that directly affects maritime educators' ability to teach emerging operational systems — confirming that faculty development investment is a prerequisite for effective maritime technology curriculum implementation.

METHOD

Research Design

This study employs a qualitative research design (Creswell & Poth, 2018; Merriam & Tisdell, 2016) examining IT/IoT operational integration and CBL educational adoption through the simultaneous perspectives of three maritime stakeholder groups. The qualitative design is appropriate for investigating governance processes, adoption dynamics, and institutional conditions — phenomena requiring contextually sensitive interpretive analysis rather than quantitative measurement of predefined variables.

Participants and Inclusion Criteria

Participants were selected through purposive criterion sampling to ensure positional authority and experiential grounding relevant to both research domains.

Maritime Industry **Professionals (n=8):** Inclusion criteria required minimum 10 years of experience in port management, shipping operations, or maritime company management, with documented direct engagement with IT or IoT systems in their operational roles.

Participants included shipping company technical directors, port operations managers, and maritime safety officers.

Maritime Lecturers and Trainers (n=12): Inclusion criteria required active teaching responsibilities in maritime engineering, navigation, or technical maritime subjects, with minimum three years of maritime vocational instruction experience. Participants taught across naval engineering, maritime management, and operational safety subjects at three Indonesian maritime polytechnics.

Graduates (n=13): Inclusion criteria required completion of a maritime engineering or nautical program within the preceding three years and minimum six months of professional maritime employment. This criterion ensured that graduates could assess both their educational preparation and their operational IT/IoT exposure as employed maritime professionals.

Table A. Participant Characteristics

Group	n	Core Qualification	Experience Range
Maritime Industry Professionals	8	Min. 10 yrs; active IT/IoT operational role	11–28 years
Lecturers and Trainers	12	Min. 3 yrs maritime engineering/navigation instruction	4–19 years
Graduates	13	Maritime polytechnic program; min. 6 months employment	7–36 months post-graduation
Total	**33**		

Data Collection

Semi-structured interviews were conducted individually with professional and lecturer participants; focus group discussions were conducted with two groups of graduates. All professional interviews were conducted face-to-face at participants' institutional or company locations. Lecturer and graduate sessions were conducted in hybrid format (face-to-face and Zoom) depending on participant availability. Sessions lasted 60 to 90 minutes, were audio-recorded with written informed consent, and were transcribed verbatim within one week.

The interview protocol addressed three domains corresponding to the research questions: IT/IoT integration in maritime operations (adoption levels, implementation barriers, effectiveness experience); CBL in maritime education (tool familiarity, usage patterns, resource and capacity constraints); and industry-education collaboration (mechanisms, adequacy, and reform priorities). Supporting structured rating scales (10-point Likert-type) were administered within each session for Indicators 1 and 2, providing triangulating descriptive data; group mean scores are reported in Tables 1 and 2. These scores supplement but do not replace the thematic analysis as the primary analytical output.

Thematic Analysis Procedure

Interview and focus group data underwent six-phase thematic analysis following Braun and Clarke (2006). Phase 1 (Familiarization): All 33 transcripts were read twice with researcher memos. Phase 2 (Open Coding): Line-by-line coding in NVivo 14 generated 156 initial codes. Phase 3 (Focused Coding): Initial codes were grouped into 14 sub-categories and consolidated into three overarching themes. Phase 4 (Theme Review): Themes were validated against the full dataset. Phase 5 (Theme Definition): Precise analytical definitions were assigned to each theme. Phase 6 (Triangulation): Interview themes were cross-referenced with structured rating data and supplementary institutional document analysis. A second independent coder coded 25 percent of the transcript corpus; Cohen's Kappa was calculated at $\kappa = 0.82$, indicating strong intercoder agreement (Landis & Koch, 1977). Member checking was conducted with one participant per stakeholder group who reviewed and confirmed preliminary theme summaries.

RESULTS AND DISCUSSION

The thematic analysis generated three overarching themes: IT/IoT integration constrained by infrastructure and standardization deficits; CBL effectiveness limited by resource and instructor capacity gaps; and industry-education collaboration as structurally underdeveloped. The following presentation integrates findings with theoretical interpretation and prior study comparison. Supporting rating data (Tables 1 and 2) provide triangulating descriptive context.

Theme 1: IT/IoT Integration — High Awareness, Structural Implementation Barriers

Finding: Maritime professionals demonstrate strong understanding of IT/IoT applications and acknowledge their operational value, but identify three structural barriers — infrastructure incompatibility, high transition costs, and regulatory lag — as preventing full-scale deployment. Supporting rating data confirm the awareness-implementation gap pattern.

Table 1. IT and IoT Integration — Participant Mean Ratings (Scale 1–10)

Sub-Indicator	Professionals (n=8)	Lecturers (n=12)	Graduates (n=13)	Overall Mean
Understanding of IT/IoT applications	8.8	7.2	7.5	7.9
Level of IT/IoT implementation	7.5	6.0	6.8	6.9
Effectiveness in operational practice	6.8	5.5	6.0	6.1

The gap between understanding (7.9 overall) and operational effectiveness (6.1 overall) — a 1.8-point differential — constitutes the study's most diagnostically significant quantitative pattern. Professional participants rated understanding highest (8.8) but effectiveness lowest relative to understanding (6.8), reflecting experienced awareness of the gap between IT/IoT potential and current operational realization.

One shipping company technical director with 22 years of experience stated:

"We have invested significantly in IoT sensors on our vessels — fuel monitoring, hull stress, engine performance. The data comes in continuously. But we do not have the analytics infrastructure to turn that data into decisions consistently. The sensors are industry-ready; our decision systems are not. The technology adoption outpaced our system capacity to use it."

A maritime lecturer with 11 years of experience in navigation systems confirmed the educational consequence:

"My students know what IoT is. They have studied the concepts. But I do not have operational IoT systems in my classroom for them to interact with. I am teaching them about technology they have never touched. The gap between understanding the concept and operating the system is very large, and education does not currently bridge it."

Interpretation: The awareness-effectiveness gap documented in Table 1 reflects a structural condition in which IT/IoT adoption has advanced faster than the institutional infrastructure — analytics platforms, data governance frameworks, and interoperability standards — necessary to convert data collection into operational decision-making value. This pattern confirms and extends Jimenez et al.'s (2022) finding that full IoT operational benefit requires sophisticated analytics capabilities beyond basic sensor installation. The lecturer quotation identifies the educational consequence directly: students learn system concepts without operational system exposure, producing declarative knowledge without the situated operational understanding that professional practice requires.

Theory: Dyagileva et al. (2020), examining digital transformation in maritime education, established that sustainable technology integration requires network-level coordination among institutions — a governance mechanism absent from both the operational and educational sides of the IT/IoT adoption challenge. Shao et al. (2022), demonstrating that IoT data visualization significantly improves business intelligence decision-making, provides the theoretical basis for why the analytics infrastructure gap the professional describes is not merely operational but strategically consequential. Wulandari and Cahyadi's (2025) confirmation that Indonesian maritime technology implementation capacity remains critically underdeveloped despite growing institutional recognition contextualizes the 6.1 effectiveness score as reflecting a systemic infrastructure deficit rather than individual adoption resistance.

Implication: Maritime companies should invest in analytics and data governance infrastructure alongside sensor deployment, ensuring that data collection investments yield operational decision-making value. Port authorities and shipping associations should develop interoperability standards for maritime IoT data formats — creating the shared data infrastructure that enables the system-to-system integration that individual company investments cannot achieve unilaterally.

Theme 2: CBL Effectiveness — High Potential, Resource and Instructor Capacity Constraints

Finding: Computer-based learning tools — virtual simulators, AR training environments, and LMS platforms — are rated positively for their educational effectiveness, but their adoption is systematically constrained by resource limitations and instructor capacity gaps that create significant disparities across institutions.

Table 2. CBL Effectiveness in Maritime Education — Participant Mean Ratings (Scale 1–10)

Sub-Indicator	Professionals (n=8)	Lecturers (n=12)	Graduates (n=13)	Overall Mean
CBL tool adoption and availability	7.0	5.8	6.5	6.4
Effectiveness for learning outcomes	8.0	7.5	7.8	7.8
Barrier-free implementation	5.5	4.8	5.5	5.3

The largest pattern in Table 2 is the gap between learning outcome effectiveness (7.8 overall) and barrier-free implementation (5.3 overall) — a 2.5-point differential that is wider than the analogous gap in Table 1. Lecturers rated barrier-free implementation lowest of all groups (4.8), reflecting educators' direct experience of the institutional constraints that prevent consistent CBL deployment.

One graduate with 18 months of professional experience as a deck officer stated:

"The simulator training we had was the most valuable part of my education. It was the only time I felt I was actually operating something — making decisions that had consequences I could see. But we only had eight hours of simulator time in the whole program. My colleagues who trained at a different polytechnic had sixty hours. The difference in our operational confidence was very clear."

A maritime trainer with nine years of experience in navigation instruction confirmed the institutional constraint:

"Students lack exposure to real sustainability practices and current technology. We have a simulator, but it models 2015 vessel systems. The shipping industry is now operating hybrid systems and digital navigation interfaces that are completely different. I cannot teach what I cannot show, and I cannot show what my institution cannot afford to acquire."

A maritime professional from a port management corporation identified the industry perspective on this gap:

"When we hire graduates, we spend the first three to six months retraining them on our actual systems. They understand the principles, but they have not operated anything like our current

port management software. If their education had included our actual platforms — or current equivalents — we would save enormous retraining time and they would be contributing much faster."

Interpretation**:** The effectiveness-barrier gap in Table 2 reflects a paradox documented across the CBL literature: educational stakeholders recognize CBL's learning outcome effectiveness (7.8) while simultaneously experiencing the institutional barriers that prevent consistent deployment (5.3). The graduate quotation — eight hours versus sixty hours of simulator time for students at different institutions — illustrates the equity dimension of this resource disparity: CBL effectiveness is not uniformly accessible but depends on the institution's resource position. The trainer quotation identifies the technology currency component: even available simulators may model outdated systems, producing students familiar with technology that is no longer in operational use.

Theory: This finding confirms Nidhom et al.'s (2025) systematic review finding that instructor digital competency is a necessary antecedent of effective CBL deployment — the trainer who "cannot teach what I cannot show" is experiencing exactly the competency-infrastructure interaction Nidhom et al. identify as the primary implementation failure mode. Komaro et al.'s (2022) documentation that digital competency is the lowest-achieving domain among Indonesian vocational lecturers provides the empirical baseline explaining why the 4.8 lecturer rating for barrier-free implementation is the lowest in Table 2. Othman et al.'s (2025) finding that effective CBL requires simultaneous investment in infrastructure, faculty capacity, and governance frameworks — not any single element alone — explains why partial institutional investments produce the inconsistent adoption patterns both Tables document. Daryono et al.'s (2023) confirmation that assessment context significantly influences competency development provides the learning science basis for why the simulator training gap between eight and sixty hours produces measurably different graduate operational confidence levels.

Implication: Maritime polytechnics should establish minimum CBL contact hour standards — including simulator time requirements calibrated to current operational technology — as formally assessed curriculum components, ensuring that resource disparities do not translate into competency disparities. The Ministry of Transportation should designate CBL infrastructure investment as a priority category within maritime education capital funding, establishing a technology currency standard that requires simulator systems to model maritime technology within a defined recency window.

Theme 3: Industry-Education Collaboration — Necessary but Structurally Underdeveloped

Finding: Industry-education collaboration is universally recognized by all three stakeholder groups as essential for aligning IT/IoT operational competency demands with CBL educational provision — yet the structural mechanisms for this collaboration are underdeveloped, defaulting to placement facilitation rather than curriculum co-design.

One maritime professional described the governance gap directly:

"We know what our new officers need to know. They need to understand our ECDIS systems, our voyage data recorders, our fuel optimization software. We would share that knowledge with the training institutions. But nobody has invited us to help design the curriculum. We provide internships. That is the extent of our formal involvement."

A senior lecturer confirmed the institutional side of the same dynamic:

"Our curriculum was last comprehensively revised four years ago. The IT systems in use in the industry have changed substantially since then. We need industry input to update the technology content — but the formal mechanism for that is an advisory board that meets once a year and reviews what already exists, not what should be added."

Interpretation: Both quotations describe the same structural gap from opposite sides: industry has knowledge and willingness to contribute that the institutional curriculum design process does not formally access. The annual advisory board model — reviewing existing curriculum rather than co-designing new content — cannot generate the continuous technology currency that maritime IT/IoT education requires.

Theory: Suyetno et al.'s (2024) finding that genuine industry co-design — not formal advisory participation — produces curriculum alignment directly explains this pattern: annual review meetings are formal partnerships without co-design function. Wahyudi et al.'s (2025) demonstration that substantive partnership quality rather than partnership formality determines educational outcome quality reinforces the point: STIP Jakarta's formal MoU relationships with industry stakeholders generate internship placements but not curriculum content — a partnership form without the curriculum function that would close the IT/IoT competency gap. Aminah et al.'s (2025) outcome-based curriculum framework provides the governance model through which maritime IT/IoT competency standards could be formally inscribed within program outcome specifications — creating the institutional mechanism that enables continuous industry content input without requiring full curriculum revision cycles. Song and Xu's (2024) warning that vocational education expansion can produce certification without operational capability when governance conditions are absent frames the risk: without governance reform, Indonesian maritime education may produce increasing numbers of graduates with IT/IoT familiarity but not operational proficiency.

Practical Implication: Maritime polytechnics should restructure industry engagement from annual advisory review to embedded continuous co-design — establishing quarterly technology update meetings with active industry technology leads, joint simulator content development projects, and competency assessment co-design with industry operational managers. These changes transform advisory relationships into governance relationships capable of sustaining technology curriculum currency.

Indicator : Integration of IT and IoT in Maritime Engineering Practices

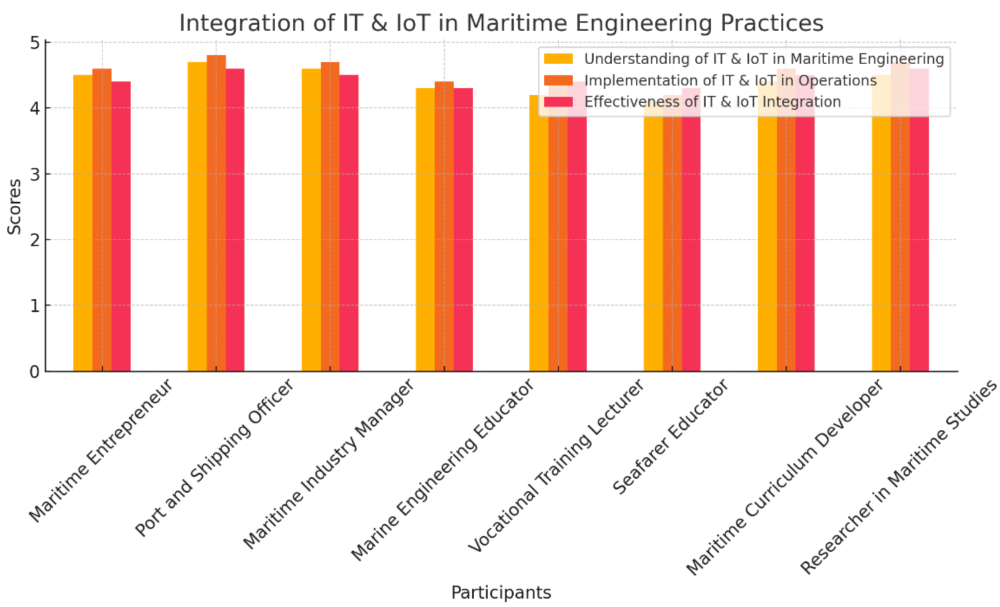

Figure 1. Integration of IT & IoT in Maritime Engineering Practices

The data from the participants reveals a strong understanding of IT and IoT technologies and their applications in maritime engineering. Maritime professionals, such as entrepreneurs, officers, and managers, consistently report high scores in their understanding of how these technologies can enhance operational efficiency, safety, and sustainability. The implementation of IT and IoT systems is rated similarly, demonstrating that maritime companies are increasingly adopting these technologies for real-time vessel monitoring, predictive maintenance, and route optimization.

However, the effectiveness of the integration of these technologies in operational practices shows slightly lower scores than the understanding and implementation ratings. This gap suggests that while the technology is well understood and adopted, its full potential has not been realized due to challenges such as outdated infrastructure, lack of compatibility across different systems, and high initial costs. The challenges identified by the participants—such as the technological gaps in port systems and the need for more specialized curriculum in maritime education—highlight the barriers that must be overcome for more seamless integration and greater operational efficiency.

Indicator : Effectiveness of Computer-Based Learning in Maritime Education

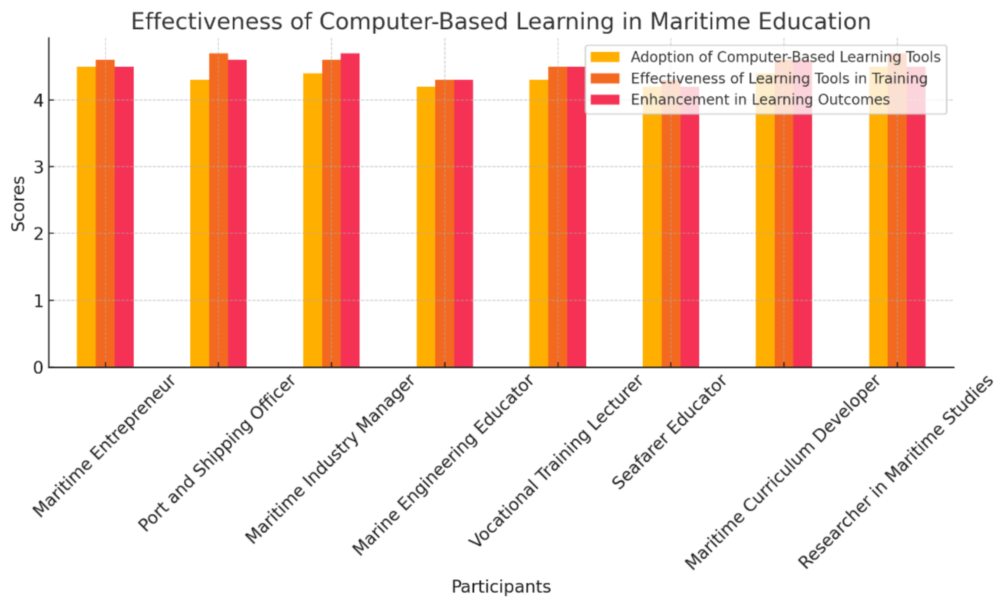

Figure 2. Effectiveness of Computer-Based Learning in Maritime Education

The second indicator examines the role of computer-based learning in enhancing maritime education, particularly in terms of training students to work with advanced technologies in the maritime sector. The data shows that the adoption of computer-based learning tools, including virtual simulations, online learning platforms, and augmented reality, is growing within maritime education institutions. The effectiveness of these learning tools is highly rated, with significant improvements in learning outcomes and a more engaging, interactive educational experience for students.

Participants, including both educators and industry professionals, acknowledge the positive impact of computer-based learning in preparing students for the technological demands of the maritime industry. The use of simulations and VR technologies, for instance, allows students to interact with complex maritime systems, gaining practical experience without the need for physical access to ships or equipment. However, challenges remain in the implementation of these technologies across all educational institutions. Limited resources, resistance to new technologies, and the need for updated content and instructor training were frequently cited as obstacles to the effective deployment of these learning tools.

Comprehensive Tables and Results Interpretation

The tables presented above reflect the scores given by participants in the study based on their experiences and perceptions of the integration of IT, IoT, and computer-based learning in maritime engineering and education. These scores are divided into three main areas: understanding of the technology, its implementation in practice, and its effectiveness in achieving desired outcomes.

For Indicator 1, participants consistently rated the understanding and implementation of IT and IoT technologies highly. However, the effectiveness scores suggest that, while there is a solid foundation for the adoption of these technologies, the maritime industry still faces challenges in optimizing their use for maximum efficiency and sustainability. These challenges primarily stem from the high costs, slow infrastructure upgrades, and lack of uniform standards across different sectors of the maritime industry.

For Indicator 2, the adoption and effectiveness of computer-based learning tools are rated positively, indicating that these technologies are becoming increasingly integral to maritime education. The significant improvement in learning outcomes demonstrates the potential of these tools to enhance students' understanding and readiness to work with modern maritime systems. Nevertheless, the barriers to full implementation, such as resource limitations and resistance from educators, suggest that more work is needed to standardize the integration of computer-based learning across educational institutions.

The results from both indicators demonstrate a strong trend toward the adoption of IT, IoT, and computer-based learning technologies in the maritime industry and educational sectors. The understanding and implementation of these technologies show considerable promise, yet their full potential is often hindered by infrastructure limitations, resistance to change, and a lack of standardized systems. These findings emphasize the need for further investment in infrastructure, curriculum updates, and professional development to ensure that the maritime sector and educational institutions are equipped to harness the full capabilities of these emerging technologies.

CONCLUSION

Answers to Research Questions and Main Findings

This study demonstrates that IT/IoT integration in Indonesian maritime operations and CBL adoption in maritime education are both constrained by the same root structural failure: inadequate governance coordination between maritime industry stakeholders and educational institutions. For RQ1, while maritime professionals demonstrate strong IT/IoT awareness (overall understanding rating 7.9), operational effectiveness scores (6.1) reveal that infrastructure incompatibility, analytics platform deficits, and regulatory lag prevent full operational realization. For RQ2, CBL is recognized as highly effective for learning outcomes (7.8) but systematically under-deployed due to resource disparities between institutions, technology currency gaps in available simulators, and instructor digital competency deficits — producing an equity dimension in which students at better-resourced institutions receive dramatically more CBL exposure. For **RQ3**, current industry-education collaboration mechanisms default to placement facilitation rather than curriculum co-design, failing to provide the continuous technology content input that maritime IT/IoT curriculum currency requires.

Scientific Contributions and Practical Recommendations

The study's principal theoretical contribution is the dual-domain analytical framework demonstrating that operational IT/IoT integration barriers and CBL implementation constraints share a common governance root cause — enabling interventions that address both domains simultaneously rather than treating them as independent technical or financial problems. This extends Suyetno et al.'s (2024) curriculum governance analysis, Wahyudi et al.'s (2025) partnership quality findings, and Nidhom et al.'s (2025) faculty development framework into the maritime IT/IoT education domain simultaneously.

Three concrete recommendations follow from the findings. First, maritime polytechnics should establish minimum CBL simulator contact hour standards calibrated to current operational technology, with Ministry of Transportation funding designated for technology currency maintenance. Second, industry-education partnerships should be redesigned from annual advisory review to quarterly co-design meetings with formal curriculum content obligations — transforming formal partnerships into governance relationships. Third, maritime companies should invest in analytics and data governance infrastructure alongside IoT sensor deployment, ensuring data collection investments yield the operational decision-making value that currently remains unrealized.

Future research should employ longitudinal designs tracking IT/IoT operational competency development under reformed CBL governance conditions. Quantitative studies measuring the relationship between simulator contact hours and operational competency outcomes would provide causal evidence for minimum hour standards. Comparative studies across ASEAN maritime education systems would test whether the dual-domain governance root cause finding is transferable across national regulatory and institutional contexts.

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