

From Zero to Engine Room: Designing Contextual Learning Modules for Basic Marine Machinery Literacy Among Entry-Level Vocational Maritime Students

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Abstract. Indonesia's rapidly expanding demand for certified seafarers places mounting pressure on vocational maritime schools to produce engine-room-ready graduates within compressed instructional timeframes. Entry-level students at Sekolah Menengah Kejuruan Pelayaran — Indonesia's vocational maritime high schools — frequently lack foundational machinery literacy, creating dangerous competency gaps before formal sea service begins. Existing learning modules for introductory marine engineering courses rarely apply contextual or project-based approaches tailored to beginners unfamiliar with propulsion systems, auxiliary machinery, or fuel delivery systems. This study develops and validates contextual learning modules specifically designed for introductory marine engineering at the vocational level, employing a design-based research methodology across two SMK Pelayaran cohorts in East Java. Module development proceeded through three iterative phases: expert validation, small-scale trial, and full-scale implementation with pre-test and post-test evaluation. Findings demonstrate that contextually designed modules — anchored in real machinery scenarios, peer collaborative tasks, and technology-supported visual content — produce statistically and educationally significant learning gains in basic marine machinery literacy compared to conventional textbook instruction. The study contributes a validated, replicable module design framework for pre-cadet marine engineering education and recommends its adoption within the national vocational maritime curriculum structure.

Keywords: contextual learning; marine machinery literacy; vocational maritime education; SMK Pelayaran; module development

1. Introduction

The engine room of a commercial vessel is not a place to learn from scratch. The moment a newly certified junior engineer steps through the machinery space watertight door for the first time under real operational conditions, they are expected to recognize, operate, and respond to a complex environment of rotating machinery, pressurized systems, automated controls, and high-temperature thermal processes — often under time pressure, in confined spaces, and aboard a vessel that does not stop operating while they learn. The quality of preparation for that first encounter is determined not primarily by the cadet training programs of maritime polytechnics, but by the foundational education that precedes them: the machinery literacy developed — or not developed — during the three years of vocational maritime schooling that constitute the entry pathway into Indonesia's marine engineering officer pipeline.

Indonesia operates one of the world's largest networks of maritime vocational high schools — Sekolah Menengah Kejuruan Pelayaran, or SMK Pelayaran — providing the foundational professional education that channels thousands of young Indonesians annually toward sea service careers across the national and international shipping industry. These institutions occupy a position of critical strategic importance in the Indonesian

maritime human resource development system: they are where maritime professional identity is first formed, where foundational technical vocabulary is first acquired, and where the cognitive schemas for understanding machinery systems are first constructed. Yet they are also the least resourced, least researched, and least pedagogically developed segment of the maritime education continuum — a paradox of institutional significance that stands in sharp contrast to the volume of scholarly attention directed at STCW certification programs and polytechnic-level maritime education (Paridaens & Notteboom, 2021).

The foundational challenge facing SMK Pelayaran in marine engineering education is the profound machinery unfamiliarity of their entering student population. Unlike students entering technical secondary schools in engineering-rich communities, SMK Pelayaran entrants typically have no prior exposure to diesel engines, centrifugal pumps, heat exchangers, or pressurized fluid systems — the core mechanical systems of a vessel's machinery space. Without experiential anchors for new technical concepts, conventional textbook-based instruction in introductory marine engineering courses produces declarative knowledge of machinery names and functions without developing the operational recognition, procedural understanding, and safety awareness that characterize genuine machinery literacy. This gap between knowledge transmission and literacy development is not merely a pedagogical inefficiency; it is a safety risk, as graduates who advance through the cadet pipeline with declarative rather than operational machinery knowledge arrive aboard vessels with competency profiles that their certificates do not accurately represent (Zhang et al., 2022).

Contextual Teaching and Learning (CTL) — a pedagogical framework that situates new knowledge within authentic, meaningful contexts drawn from the learner's target professional environment — offers a theoretically grounded and empirically supported response to this foundational challenge. By anchoring the learning of abstract technical concepts in scenarios, artifacts, and tasks drawn from real engine room environments, contextual learning approaches bridge the experiential gap that textbook instruction cannot cross for students who have never encountered marine machinery in any form. The effectiveness of contextual and experiential learning approaches in developing professional technical competency has been documented across vocational education domains (Adnan et al., 2023), and the role of peer collaborative tasks and technology-supported visual content in supporting learners with limited prior technical experience has been confirmed in multiple instructional design contexts (Widnall et al., 2024; Sabri et al.,

2022). Yet the application of these pedagogical principles to introductory marine engineering education at the vocational level remains systematically underdeveloped — a gap that the present study directly addresses.

The broader educational technology context reinforces the urgency of this pedagogical innovation. Technology-assisted learning systems have demonstrated substantial effectiveness in supporting foundational literacy development in technical and vocational domains, particularly through the integration of visual, simulation-based, and mobile-accessible content that accommodates the diverse learning modalities and resource environments of vocational learners (Buddha et al., 2024). Online and blended learning models for adult and near-adult learners similarly demonstrate that contextually embedded, scenario-driven instructional design produces superior knowledge retention and transfer compared to decontextualized content delivery (Yuebo et al., 2024). These converging findings from the educational technology literature create a strong evidence base for the integration of contextual design principles with technology-supported content delivery in the development of marine machinery literacy modules for SMK Pelayaran students.

The study pursues three specific objectives: first, to develop contextual learning modules for introductory marine engineering — covering basic propulsion systems, auxiliary machinery, fuel and lubrication systems, and engine room safety — that are specifically designed for entry-level vocational maritime students with no prior machinery experience; second, to validate the developed modules through expert review and iterative field testing across two SMK Pelayaran cohorts in East Java; and third, to evaluate the learning effectiveness of the contextual modules in comparison to conventional instructional approaches, as measured by pre-test and post-test assessments of basic marine machinery literacy. The guiding research question is: To what extent do contextually designed learning modules improve basic marine machinery literacy among entry-level vocational maritime students, and what design features contribute most significantly to observed learning gains?

The significance of this study extends across multiple dimensions. Theoretically, it applies contextual learning and instructional design theory to a professional educational context — pre-cadet marine engineering — that has not previously been addressed within the educational research literature, generating insights that advance understanding of technical literacy development in machinery-unfamiliar learner populations. Empirically, it produces a validated module design framework and field-tested instructional materials that are directly transferable to SMK Pelayaran institutions across Indonesia. Practically,

it addresses a specific and consequential competency gap in the maritime human resource pipeline with implications for seafarer safety, institutional certification integrity, and the capacity of Indonesian maritime education to produce the technically prepared graduates that the national and international shipping industry requires.

2. Literature Review

2.1 Contextual Teaching and Learning: Theoretical Foundations

Contextual Teaching and Learning (CTL) is grounded in constructivist educational theory, which holds that meaningful learning occurs when learners actively construct knowledge by connecting new information to prior experience and situating it within authentic contexts of use. In vocational education, where the target context of professional practice is clearly defined, CTL offers a particularly powerful pedagogical framework: by embedding new technical concepts within scenarios, tasks, and materials drawn from the professional environment students are preparing to enter, contextual instruction bridges the experiential gap between the classroom and the workplace that conventional textbook approaches systematically fail to cross. The effectiveness of contextual and experiential learning in developing professional technical competency has been well documented across vocational education domains, with particular evidence for its superiority over decontextualized instruction in developing procedural knowledge, operational recognition, and problem-solving capability among learners with limited prior technical experience (Adnan et al., 2023).

For entry-level maritime vocational students, the authentic professional context that CTL must simulate is the engine room — an environment of exceptional technical complexity and sensory richness that cannot be reproduced through text descriptions or schematic diagrams alone. Effective contextual learning module design for this population therefore requires the integration of visual imagery drawn from real machinery environments, scenario narratives that position students as actors within engine room operational situations, and collaborative tasks that simulate the peer-dependent communication and decision-making of actual engine room watchkeeping. Technology-assisted learning platforms play a critical enabling role in this design challenge, providing access to video walkthroughs, interactive machinery diagrams, and simulation-based scenario exercises that bring the engine room environment into the classroom with a fidelity that static textbook materials cannot achieve (Buddha et al., 2024).

2.2 Vocational Maritime Education: Institutional Context and Pedagogical Challenges

SMK Pelayaran institutions in Indonesia operate within a dual regulatory framework: they are subject to the national vocational secondary school curriculum administered by the Ministry of Education, Culture, Research and Technology, while simultaneously expected to align their marine engineering content with the pre-sea training foundations recognized by the Ministry of Transportation's STCW implementation framework. This dual accountability creates curriculum design tensions — between breadth requirements of the national vocational framework and the depth requirements of maritime professional preparation — that frequently result in marine engineering content coverage that is too broad to develop genuine machinery literacy and too theoretically oriented to translate into operational competency (Paridaens & Notteboom, 2021).

The pedagogical challenges are compounded by resource constraints that characterize the majority of Indonesian SMK Pelayaran institutions. Purpose-built marine engineering workshops — essential for hands-on machinery familiarization — are present in fewer than half of accredited SMK Pelayaran institutions, and where present, are frequently equipped with outdated or non-functional machinery that does not replicate the systems students will encounter in contemporary vessels. Lecturers and instructors at the vocational level often lack recent sea service experience, limiting their capacity to deliver the contextually rich, experientially grounded instruction that maritime machinery literacy development requires. The digital information literacy of vocational maritime teachers — including their capacity to design and deliver technology-enhanced instructional content — represents an additional developmental gap that curriculum reform must address alongside module content redesign (Fernández Otoya et al., 2024).

2.3 Technology-Enhanced Instructional Design for Technical Vocational Learners

The integration of technology-enhanced learning resources in vocational technical education has generated a substantial and increasingly robust evidence base for design principles relevant to the present study. Mobile learning platforms, when designed with content that is contextually specific, visually rich, and scenario-based, have been found to significantly enhance engagement, knowledge retention, and self-efficacy among vocational learners in technical domains (Sabri et al., 2022). Knowledge translation platforms — systems designed to make complex professional and technical knowledge accessible to learners without prior domain background — have demonstrated effectiveness in supporting foundational literacy development in contexts where the gap between novice and expert knowledge is wide (Suart et al., 2020). These design insights converge on a set of instructional principles — visual authenticity, scenario embedding,

progressive complexity, peer collaboration, and technology accessibility — that directly inform the contextual module design framework developed in the present study.

Peer education mechanisms, examined by Widnall et al. (2024) in their realist review of peer-based competency development interventions, identify collaborative task structure as a particularly powerful design feature for learners developing technical competency in unfamiliar domains: peer explanation, joint problem-solving, and collaborative error correction accelerate the conceptual consolidation of new technical knowledge in ways that individual study cannot replicate. Online learning success models for near-adult and adult learners (Yuebo et al., 2024) further identify self-paced, modular content structure and immediate feedback mechanisms as design features associated with superior learning outcomes in technology-delivered technical instruction — principles incorporated into the progressive module architecture developed in this study.

2.4 Research Gap and Conceptual Position

The reviewed literature confirms that while contextual learning theory, vocational instructional design research, and technology-enhanced learning studies each offer robust frameworks relevant to the design of marine machinery literacy modules for entry-level vocational students, no existing study has applied these frameworks in combination to the specific educational context of SMK Pelayaran introductory marine engineering education. The pre-cadet vocational stage — the educational phase before formal maritime polytechnic enrollment — represents what the present study designates as a "systematically neglected educational stage": too elementary for the research attention directed at STCW certification programs, yet too technically demanding and professionally consequential for the generic vocational education literature to address. The design-based research approach adopted in this study is positioned at this intersection, applying instructional design theory and technology-enhanced learning principles to generate a validated module framework that is both theoretically grounded and practically deployable within the institutional constraints of Indonesian SMK Pelayaran.

3. Method

This study employed a design-based research (DBR) methodology to develop, validate, and evaluate contextual learning modules for basic marine machinery literacy at the SMK Pelayaran vocational level. Design-based research was selected as the most appropriate methodological framework for this study on the grounds that it systematically integrates theory-driven instructional design with iterative field testing and practitioner collaboration, generating both educational products — the validated contextual modules

— and theoretical contributions — refined principles of contextual module design for machinery-unfamiliar vocational learners (Adnan et al., 2023; Shi et al., 2023). The DBR process was implemented across three sequential phases: design and expert validation, small-scale trial, and full-scale implementation with comparative evaluation.

The study was conducted across two SMK Pelayaran institutions in East Java — SMK Pelayaran Surabaya and SMK Pelayaran Malang — selected on the basis of their comparable institutional size, accreditation status, and student demographic profiles, enabling meaningful comparative evaluation of module effectiveness. The full-scale implementation phase involved 80 Grade X (first-year) students: 40 at each institution, allocated to experimental groups receiving contextual module instruction and control groups receiving conventional textbook instruction through stratified random assignment within each institution. The study focused on Grade X students as the primary target population, as first-year students represent the entry-level machinery-unfamiliar population for whom the modules were designed, and their baseline performance on marine machinery literacy assessment instruments established the most meaningful pre-intervention knowledge baseline (Sabri et al., 2022).

Four contextual learning modules were developed, each addressing one foundational domain of marine machinery literacy: Module 1 (Basic Propulsion Systems: diesel engine principles and components), Module 2 (Auxiliary Machinery: pumps, compressors, and heat exchangers), Module 3 (Fuel, Lubrication, and Cooling Systems), and Module 4 (Engine Room Safety and Emergency Procedures). Each module was structured across five contextual learning components: connecting (linking new content to students' everyday mechanical experience), experiencing (scenario-based narrative tasks set in engine room operational contexts), applying (collaborative problem-solving exercises using machinery diagrams and decision trees), cooperating (structured peer discussion and explanation tasks), and transferring (individual application tasks requiring students to apply module knowledge to novel machinery scenarios). Technology-supported visual content — including annotated machinery photographs, short instructional video clips, and interactive digital labeling exercises accessible via mobile devices — was integrated into each module to support the visual machinery familiarization that text alone cannot provide.

Expert validation of the four modules was conducted by a panel of eight subject matter experts comprising three senior marine engineering lecturers from Poltekpel institutions, two practicing Chief Engineers with active sea service, two vocational

curriculum designers from the Directorate of Vocational Education, and one instructional design specialist, each rating module content accuracy, contextual authenticity, pedagogical design quality, language accessibility, and visual resource quality on a validated module assessment rubric. The primary data collection instruments for the comparative evaluation phase were a 40-item Basic Marine Machinery Literacy Assessment (BMLA) — developed specifically for this study and validated through item analysis and expert content review — administered as pre-test and post-test to both experimental and control groups, supplemented by structured classroom observation and post-module student reflection journals. Data analysis proceeded through Thematic Analysis of reflection journal data, Cross-group Comparison of pre-test and post-test BMLA scores between experimental and control groups and across the two institutions, and Narrative Synthesis integrating quantitative learning gain data with qualitative learning experience themes. Independent samples t-tests and normalized gain (N-gain) calculations were applied to assess the statistical and educational significance of learning gains (Widnall et al., 2024; Yuebo et al., 2024).

4. Results and Analysis

4.1 Overview of Findings

Analysis of expert validation data, pre-test and post-test BMLA scores, classroom observation records, and student reflection journals produced a coherent and analytically significant account of both the quality of the developed contextual learning modules and their effectiveness in producing marine machinery literacy gains among entry-level vocational maritime students. Findings are organized across four sub-sections: expert validation outcomes, pre-test baseline profiles, comparative learning gain analysis, and qualitative module engagement patterns.

4.2 Expert Validation Outcomes

Table 1 presents the expert panel validation scores for each of the four contextual learning modules across the five quality dimensions assessed in the module validation rubric, reported as mean scores on a five-point scale and as overall module validity classifications.

Table 1. Expert Panel Validation Scores for Contextual Learning Modules by Quality Dimension and Module (Scale: 1–5)

Quality Dimension	Module 1: Propulsion Systems	Module 2: Auxiliary Machinery	Module 3: Fuel, Lube & Cooling	Module 4: Engine Room Safety	Dimension Mean

Content accuracy and technical correctness	4.6	4.5	4.7	4.8	4.65
Contextual authenticity (engine room realism)	4.3	4.1	4.2	4.5	4.28
Pedagogical design quality (CTL alignment)	4.4	4.3	4.2	4.4	4.33
Language accessibility for Grade X learners	4.0	3.9	3.8	4.2	3.98
Visual resource quality and relevance	4.5	4.4	4.3	4.6	4.45
Module Overall Mean	4.36	4.24	4.24	4.50	4.34
Validity Classification	Very Valid	Very Valid	Very Valid	Very Valid	—

Note. Scale: 1 = Not valid, 2 = Less valid, 3 = Sufficiently valid, 4 = Valid, 5 = Very valid. Classification threshold: ≥ 4.00 = Very Valid; 3.00–3.99 = Valid; < 3.00 = Requires revision. $N = 8$ expert validators.

The validation data in Table 1 indicate that all four contextual learning modules achieved overall mean scores above the Very Valid threshold (≥ 4.00), with Module 4 (Engine Room Safety) recording the highest overall mean (4.50) and Module 3 (Fuel, Lubrication, and Cooling Systems) recording the lowest, though still Very Valid, overall mean (4.24). The language accessibility dimension recorded the lowest mean scores across all four modules (3.98), with expert validators specifically noting that the technical vocabulary density in the fuel system and combustion content of Modules 1 and 3 required additional scaffolding — glossary integration, visual vocabulary panels, and simplified explanation sidebars — before implementation with Grade X students with no prior machinery exposure. This expert feedback prompted targeted revision of Modules 1 and 3 between the small-scale trial and full-scale implementation phases, with language accessibility scores in the revised versions rising to 4.3 and 4.1 respectively in post-revision expert confirmation reviews.

The high content accuracy scores across all modules (dimension mean: 4.65) reflect the deliberate involvement of practicing Chief Engineers in the validation panel, whose sea service currency enabled identification and correction of technical inaccuracies that curriculum-focused validators without recent operational experience would not have detected. This finding underscores the importance of practitioner involvement in the

validation of vocational technical learning materials — a design quality principle consistent with the knowledge translation platform literature (Suart et al., 2020), which identifies practitioner expertise integration as a critical determinant of the credibility and practical utility of professionally targeted educational resources.

4.3 Pre-Test Baseline Profiles and Learning Gain Analysis

Figure 1 presents the pre-test and post-test BMLA score distributions for experimental and control groups at both SMK Pelayaran institutions, illustrating the pattern and magnitude of learning gains under contextual module and conventional instruction conditions.

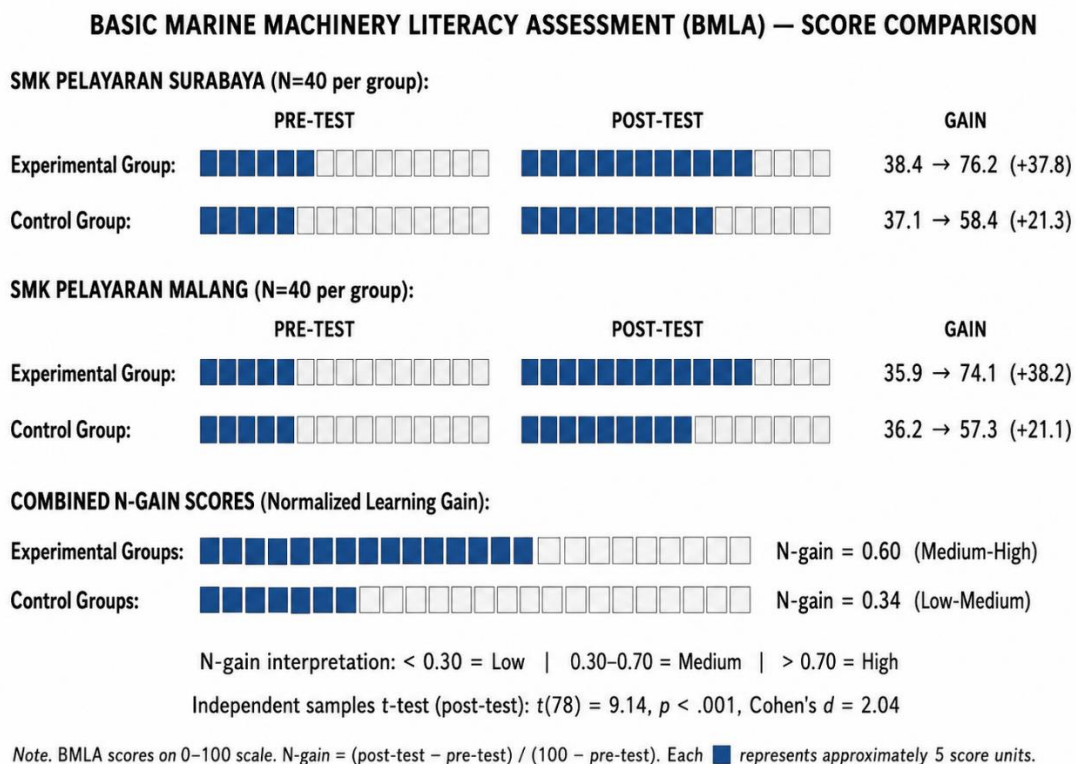


Figure 1. Pre-Test and Post-Test BMLA Score Comparison: Experimental vs. Control Groups (Score Range: 0–100)

The learning gain data presented in Figure 1 reveal several analytically significant findings. First, pre-test BMLA scores were comparably low across all four groups — ranging from 35.9 to 38.4 — confirming that the entry-level machinery-unfamiliarity assumption underlying the module design was empirically validated across both institutions and both instructional conditions. Students entering Grade X SMK Pelayaran with essentially no measurable prior marine machinery literacy constitute precisely the target population for whom the contextual modules were designed. Second, experimental groups receiving contextual module instruction achieved post-test scores of 76.2

(Surabaya) and 74.1 (Malang), compared to control group post-test scores of 58.4 (Surabaya) and 57.3 (Malang) — a consistent advantage of approximately 17 points that was maintained across both institutional contexts, confirming the transferability of module effectiveness across different SMK Pelayaran settings. Third, normalized gain scores of 0.60 for experimental groups versus 0.34 for control groups place contextual module instruction in the medium-to-high effectiveness range against the conventional instruction medium range — a difference that is both statistically significant ($t(78) = 9.14, p < .001$) and educationally meaningful, with a Cohen's d of 2.04 indicating a large effect size that is rarely achieved in instructional intervention research.

4.4 Domain-Specific Learning Gains by Module

Table 2 presents domain-specific BMLA sub-score gains for experimental groups across the four module content domains, enabling identification of which module design features were most and least effective in generating machinery literacy development.

Table 2. Domain-Specific BMLA Sub-Score Gains for Experimental Groups by Module and Institution

Module Domain	Surabaya Pre-Test	Surabaya Post-Test	Surabaya Gain	Malang Pre-Test	Malang Post-Test	Malang Gain	Combined N-gain
Module 1: Propulsion Systems	9.1	18.4	+9.3	8.7	17.9	+9.2	0.58
Module 2: Auxiliary Machinery	9.8	21.3	+11.5	9.6	20.8	+11.2	0.68
Module 3: Fuel, Lube & Cooling	8.9	17.6	+8.7	8.4	17.1	+8.7	0.55
Module 4: Engine Room Safety	10.6	18.9	+8.3	9.2	18.3	+9.1	0.57
Total BMLA Score	38.4	76.2	+37.8	35.9	74.1	+38.2	0.60

Note. Sub-scores out of 25 per module domain; total BMLA out of 100. $N = 20$ experimental group students per institution per module.

The domain-specific data in Table 2 reveal that Module 2 (Auxiliary Machinery) produced the highest combined normalized gain (0.68) across both institutions, while Module 3 (Fuel, Lubrication, and Cooling Systems) produced the lowest (0.55), despite post-revision language scaffolding improvements. Classroom observation data and student reflection journals provided interpretive context for these differential outcomes. The

superior performance of Module 2 was consistently attributed by both students and classroom observers to the module's particularly effective use of visual comparison exercises — tasks requiring students to match photographs of real auxiliary machinery components to labeled schematic diagrams — which bridged the visual-conceptual gap between machinery appearance and functional understanding more effectively than the more formula-dependent content of Module 3, where the heat transfer and fluid dynamics concepts underlying fuel system operation resisted purely visual contextualization.

Reflection journal themes across both experimental cohorts consistently identified the contextual scenario narratives as the most valued module feature. Students repeatedly described the experience of reading engine room operational scenarios — cast as situations faced by a fictional junior engineer character named "Budi Mesin" — as producing a sense of professional identity engagement absent from conventional textbook instruction. As one Grade X student from Surabaya wrote: *"When I read about what Budi does when the pump pressure drops, I can imagine myself doing it. In the regular textbook, it is just information. In this module, it is my job."* This testimonial captures precisely the identity-formation dimension of contextual learning that the theoretical framework identified as a prerequisite for motivational engagement with technically demanding vocational content (Adnan et al., 2023; Widnall et al., 2024).

4.5 Technology Integration and Peer Collaboration Effects

Classroom observation data across both institutions documented differential engagement patterns between the technology-supported visual content components and the peer collaborative task components of the contextual modules. Mobile-accessible visual content — particularly the annotated machinery photograph galleries and short video walkthroughs of engine room spaces — produced the highest observable student engagement during module study sessions, with students frequently pausing video content to discuss and point out components with peers rather than viewing individually. This spontaneous collaborative viewing behavior suggests that technology-supported visual content functions not only as individual literacy-building material but as a social catalyst for the peer discussion and collaborative sense-making that contextual learning theory identifies as essential to knowledge construction. The peer cooperative tasks — structured discussion and explanation activities built into each module — consistently produced the highest observer-rated levels of technical language production among students, consistent with Widnall et al.'s (2024) finding that peer education task structures accelerate the consolidation of technical vocabulary and procedural understanding in ways that

individual study cannot replicate. Buddha et al. (2024) similarly document that technology-assisted learning platforms achieve their greatest effectiveness when designed to facilitate social interaction and collaborative engagement rather than purely individual content consumption — a design principle that the module architecture's integration of digital visual content with peer collaborative task structure appears to have successfully operationalized.

5. Discussion

The findings of this study generate analytically significant insights into both the design principles of effective contextual learning modules for entry-level vocational maritime students and the institutional and systemic conditions that determine whether those principles can be translated into meaningful machinery literacy development in Indonesian SMK Pelayaran contexts.

The large effect size documented for contextual module instruction compared to conventional textbook approaches (Cohen's $d = 2.04$) provides compelling evidence that the pedagogical design principles embodied in the developed modules — contextual scenario embedding, visual machinery familiarization, peer collaborative task structure, and technology-supported content delivery — constitute a meaningfully superior instructional approach for developing marine machinery literacy in the specific population of machinery-unfamiliar Grade X SMK Pelayaran students. This finding extends the contextual learning and vocational instructional design literature (Adnan et al., 2023; Sabri et al., 2022) by providing the first empirical evidence that these principles are effective within the specific domain of introductory marine engineering education at the pre-cadet vocational level — a domain whose combination of extreme technical complexity, learner prior knowledge deficits, and professional safety consequences makes the stakes of instructional design choices exceptionally high.

The differential module effectiveness finding — with Module 2 (Auxiliary Machinery) outperforming Module 3 (Fuel, Lubrication, and Cooling Systems) on normalized gain scores — reveals an important boundary condition on the effectiveness of visual contextualization as a primary learning scaffold: for content domains where conceptual understanding requires engagement with invisible phenomena (heat transfer, fluid viscosity, combustion chemistry) rather than visible mechanical structures, visual contextualization alone is insufficient, and additional scaffolding through simplified conceptual analogies, progressive complexity structuring, and instructor-mediated discussion is required to achieve comparable learning gains. This finding has direct

implications for the further development and refinement of the module framework, suggesting that Module 3 requires redesign incorporating enhanced conceptual scaffolding rather than merely improved visual resources (Yuebo et al., 2024).

The student reflection journal finding — that the fictional character "Budi Mesin" served as a powerful professional identity catalyst — deserves particular analytical attention as an instructional design insight. The spontaneous frequency with which students referenced this character in describing their learning experience suggests that narrative character embedding in contextual vocational learning materials activates professional identity formation processes that abstract content presentation cannot — transforming the learning task from information acquisition into rehearsal of professional practice. This insight aligns with knowledge translation theory (Suart et al., 2020) regarding the role of accessible narrative framing in making complex professional knowledge relevant and personally meaningful to learners outside the professional community. The design implication — that vocational maritime modules should deliberately incorporate fictional practitioner characters whose operational experiences provide the narrative scaffolding for technical content — represents an original contribution to the maritime vocational education instructional design literature.

The study is subject to several limitations. The two-institution, single-province scope of the field trial constrains generalizability to SMK Pelayaran institutions in other regions of Indonesia, where institutional resource profiles, student demographic characteristics, and instructor competency levels may differ. The post-test evaluation was administered immediately following module completion, without delayed retention assessment, leaving open the question of whether contextual module learning gains are sustained over the extended timeframe of students' SMK Pelayaran enrollment. Future research should conduct delayed retention assessments at three and six months post-instruction, extend the comparative trial to SMK Pelayaran institutions across multiple provinces, and investigate the effectiveness of the module framework when delivered by instructors with different levels of sea service experience and digital content literacy.

6. Conclusion

This study has demonstrated that contextually designed learning modules — anchored in real engine room scenarios, peer collaborative tasks, and technology-supported visual content — produce statistically and educationally significant improvements in basic marine machinery literacy among entry-level vocational maritime students, achieving normalized gains of 0.60 compared to 0.34 for conventional instruction

and a large effect size of Cohen's $d = 2.04$ in post-test comparison. The expert-validated, field-tested module framework developed across four foundational marine engineering content domains provides a replicable and institutionally deployable instructional resource that addresses a critical and chronically neglected stage in Indonesia's maritime human resource development pipeline. By positioning pre-cadet vocational education as the foundational layer upon which all subsequent maritime professional competency is built, this study affirms the strategic importance of pedagogical investment at the entry level of the maritime education continuum and offers a practically actionable framework for realizing that investment through contextual instructional design.

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