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AI-Powered Adaptive Learning Media for ECDIS Training in Indonesian Maritime Education Management (Digital Navigation Pedagogy)

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ABSTRACT

The rapid digitalization of maritime bridge operations demands comprehensive transformation in nautical deck officer education and maritime training management systems. This qualitative design-based research investigates the development, implementation, and management effectiveness of AI-powered adaptive learning media integrating ECDIS simulators, virtual reality navigation scenarios, and intelligent tutoring systems across seven Indonesian maritime academies under Ministry of Transportation governance. Guided by four objectives spanning platform design, organizational management analysis, competency evaluation, and framework development the study employed purposeful multi-stakeholder sampling involving 520 nautical students, 95 maritime technology instructors, 68 shipping company officers, and 42 educational specialists across three iterative development cycles. Data were generated through in-depth semi-structured interviews, focus group discussions, classroom observations, document analysis, and thematic analysis, with trustworthiness ensured through member checking and multi-source triangulation. Findings reveal substantial navigational competency enhancements in ECDIS operational proficiency, spatial awareness, and technology integration skills, while simultaneously demonstrating that these gains are contingent upon systemic organizational management conditions including strategic leadership commitment, dedicated resource allocation, sustained instructor professional development, and robust sustainability mechanisms. Addressing a gap in existing literature on technology implementation within non-university, sector-ministry-governed maritime education, this study contributes the Maritime Technology-Enhanced Learning (M-TEL) Framework: an evidence-based implementation model offering actionable guidelines for maritime institutions and Ministry of Transportation policy officials pursuing pedagogically effective, organizationally feasible, and institutionally sustainable technology-enhanced education.

Keywords: Adaptive Learning Media; ECDIS Training; Maritime Education Management; Nautical Deck Education; Organizational Implementation.

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1. INTRODUCTION

The contemporary maritime industry witnesses unprecedented technological transformation as bridge operations transition from traditional chart-based navigation to sophisticated Electronic Chart Display and Information Systems (ECDIS), integrated navigation platforms, and artificial intelligence-assisted decision-support technologies, fundamentally challenging existing

maritime education management paradigms and institutional governance structures (Fan et al., 2021). This technological revolution not only reshapes competency requirements for nautical deck officers but also demands comprehensive transformation of educational management systems, curriculum development processes, resource allocation strategies, and quality assurance mechanisms within maritime training institutions struggling to balance regulatory compliance, technological innovation, and sustainable institutional development (Zhang et al., 2022). The management challenge intensifies as maritime education institutions globally, and particularly in developing maritime nations such as Indonesia, confront the dual imperatives of adopting technology-based learning media while simultaneously transforming organizational structures, leadership practices, and administrative systems necessary to effectively implement, sustain, and continuously improve technology-enhanced training programs (Munim et al., 2021).

Indonesian maritime education management confronts particularly complex challenges as the nation's maritime academies operate under Ministry of Transportation governance rather than traditional education ministry oversight, creating distinctive organizational contexts characterized by transportation sector regulatory frameworks, vocational training orientations, industry partnership requirements, and administrative structures fundamentally different from conventional university systems (Nguyen et al., 2023). This unique governance arrangement generates both opportunities and constraints for technology-based learning media implementation: opportunities arise from direct industry connections, practical training emphasis, and alignment with national maritime development objectives, while constraints emerge from bureaucratic rigidities, limited institutional autonomy, resource allocation mechanisms prioritizing operational transportation functions over educational innovation, and regulatory frameworks designed for traditional training methodologies rather than technology-enhanced pedagogical approaches (Pazouki et al., 2022). Current statistics reveal alarming deficiencies in both technological infrastructure and management capacity: 73% of Indonesian maritime academy navigation laboratories lack integrated ECDIS training systems, 89% of nautical instructors report inadequate preparation for technology-based teaching methodologies, institutional technology adoption decision-making processes remain largely top-down without adequate educator participation, and shipping industry surveys indicate 58% of Indonesian deck officer graduates require extensive remedial technology training before bridge assignment a competency gap costing employers approximately USD 15,000 per officer while simultaneously revealing maritime education management failures to align training outputs with industry requirements (Mallam et al., 2021).

These challenges intensify as the International Maritime Organization's mandatory ECDIS training requirements (IMO Model Course 1.27) demand not only sophisticated technology-based learning environments but also comprehensive educational management systems ensuring systematic curriculum integration, instructor professional development, quality assurance processes, and continuous improvement mechanisms organizational capabilities largely absent in Indonesian maritime academies where management practices remain oriented toward conventional classroom-based instruction rather than technology-mediated learning ecosystems (Sharma & Nazir, 2022). Furthermore, effective technology-based learning media implementation requires sophisticated change management processes, strategic resource mobilization, collaborative governance structures involving educators and industry stakeholders, and organizational learning cultures supporting innovation and experimentation management competencies inadequately developed in maritime institutions traditionally characterized by hierarchical decision-making, risk-averse cultures, and limited experience with educational

technology adoption (Jiang & Lu, 2024). The management complexity extends beyond initial technology acquisition to encompass long-term sustainability challenges including technology maintenance, content updates, instructor capacity building, learner support systems, assessment alignment, and evidence-based effectiveness evaluation organizational functions requiring dedicated resources, specialized expertise, and institutional commitment often unavailable in resource-constrained maritime education contexts (Sellberg et al., 2022).

This research addresses the critical problem: How can maritime education institutions effectively develop, implement, and manage AI-powered adaptive learning media for nautical deck officer education within the distinctive organizational contexts, resource constraints, and governance frameworks characteristic of Indonesian maritime academies under Ministry of Transportation oversight? The study pursues four specific objectives that bridge technological innovation with educational management effectiveness. First, to systematically develop an AI-powered adaptive learning platform integrating ECDIS simulation, virtual reality navigation scenarios, and intelligent tutoring systems through participatory design processes involving maritime educators, technology specialists, and industry practitioners, ensuring technological solutions align with pedagogical requirements, institutional capacities, and regulatory frameworks (Zhou et al., 2023). Second, to investigate organizational management factors including leadership practices, resource allocation mechanisms, change management approaches, instructor professional development strategies, and curriculum integration processesthat facilitate or hinder effective technology-based learning media implementation within maritime education institutions (Wang et al., 2022). Third, to evaluate the effectiveness of AI-powered adaptive learning media in enhancing nautical competency development, examining not only individual learning outcomes but also institutional management efficiency, resource utilization optimization, and alignment between educational outputs and maritime industry requirements (Li et al., 2023). Fourth, to develop evidence-based management frameworks, implementation guidelines, and policy recommendations enabling maritime education institutions and Ministry of Transportation education directorates to systematically adopt, sustain, and continuously improve technology-based learning media within organizational contexts characterized by limited resources, competing priorities, and regulatory constraints (Kim et al., 2022).

The research holds critical importance for multiple stakeholder communities within maritime education and training management domains. For maritime academy administrators and educational managers, this study provides empirical evidence and practical frameworks addressing the organizational challenges of technology adoption, offering implementation roadmaps that acknowledge institutional realities while pursuing educational innovation objectives (Ahsan et al., 2021). For Ministry of Transportation policy officials, the research generates evidence-based recommendations for regulatory adaptations, resource allocation strategies, and quality assurance mechanisms supporting technology-enhanced maritime education while maintaining STCW compliance and national maritime development objectives (Ramos et al., 2022). For maritime educators, the study offers insights into effective technology integration practices, professional development pathways, and pedagogical approaches optimizing learning media effectiveness within practical teaching contexts (Sandhåland et al., 2021). For the broader maritime education research community, this investigation contributes theoretical frameworks bridging educational technology scholarship, organizational change management theory, and maritime training domain expertise addressing significant knowledge gaps regarding technology implementation in specialized vocational education contexts under non-traditional governance structures (Hontvedt & Arnseth, 2022).

This research employs a qualitative-dominant design-based research methodology acknowledging that technology-based learning media development and organizational implementation represent complex socio-technical processes requiring iterative refinement based on stakeholder experiences, contextual realities, and emergent challenges rather than linear implementation of predetermined technical solutions (Anderson & Shattuck, 2012). The research unfolds across three development cycles spanning 18 months, with each cycle incorporating collaborative design, prototype development, implementation testing, qualitative data collection, and refinement phases. The study involves purposefully selected participants representing diverse stakeholder perspectives essential for comprehensive understanding of technology implementation within maritime education management contexts: 520 nautical students experiencing technology-based learning media, 95 maritime technology instructors navigating pedagogical transformation, 68 shipping company officers providing industry requirements perspectives, and 42 educational technology specialists and maritime academy administrators offering organizational management insights (Dahl et al., 2021). Qualitative data collection employs in-depth semi-structured interviews exploring lived experiences of technology adoption, focus group discussions examining collaborative implementation processes, classroom observations documenting technology-mediated teaching practices, document analysis of institutional policies and management procedures, and thematic analysis categorizing data into competency development themes, organizational management factors, implementation challenge patterns, and sustainability considerations (Jensen et al., 2023). This methodological approach generates rich contextual understanding of how technology-based learning media function within complex organizational ecosystems, revealing the intricate relationships between technological features, pedagogical practices, management processes, and educational outcomes essential for developing transferable implementation frameworks applicable across diverse maritime education contexts (Nazir et al., 2021).

2. RESEARCH METHOD

This research employed a qualitative-dominant design-based research (DBR) methodology, grounded in the recognition that developing and implementing AI-powered adaptive learning media within complex institutional environments requires iterative, context-sensitive refinement rather than linear execution of predetermined technical solutions (McKenney & Reeves, 2019). DBR was selected because it systematically bridges theoretical knowledge generation with practical problem-solving, producing both transferable design principles and implementable management frameworks objectives well-suited to the socio-technical complexities of maritime education technology adoption (Anderson & Shattuck, 2012).

2.1 Research Design and Cycle Structure

The study unfolded across three iterative development cycles spanning 18 months, each comprising four phases: collaborative design, prototype development and implementation, qualitative data collection and analysis, and reflective refinement. In Cycle 1, needs assessment interviews with instructors, administrators, and industry representatives informed initial platform design, surfacing competency gaps, technological requirements, and organizational constraints across participating institutions. Cycle 2 focused on pilot implementation across three academies, with classroom observations and instructor reflective journals capturing emergent pedagogical challenges and management adaptation processes. Cycle 3 extended full implementation to all seven academies, concentrating on evaluating sustainability mechanisms and institutional management effectiveness under real operational conditions. Readiness to

advance between cycles was determined through thematic saturation and deliberate stakeholder consultation, ensuring each refinement was empirically grounded rather than schedule-driven.

2.2 Participants

Participants were selected through purposeful sampling across seven Indonesian maritime academies under Ministry of Transportation governance, chosen to represent institutional variation in resource levels, geographic location, and organizational culture (Creswell & Poth, 2018). Four stakeholder groups participated, as summarized in Table 1.

Table 1. Research Participant Summary

Stakeholder Group	n	Primary Role in Study
Nautical students	520	Primary learners; evidence of competency development outcomes
Maritime technology instructors	95	Frontline implementers; pedagogical and management perspectives
Shipping company officers	68	Industry stakeholders; graduate competency assessment
Educational specialists and administrators	42	Organizational management and institutional policy insights

2.3 Data Collection

Data were generated through four complementary methods aligned with the DBR cycle structure. Semi-structured interviews served as the primary instrument, systematically exploring participant experiences of technology adoption, implementation challenges, and management processes while maintaining flexibility to pursue emergent themes (Rubin & Rubin, 2012). Focus group discussions facilitated collaborative sense-making among participant groups, generating collective perspectives on implementation dynamics unavailable through individual interviews alone (Hareide et al., 2021). Classroom observations documented technology-mediated teaching practices, student engagement patterns, and instructor facilitation approaches during live learning sessions (Sandhåland et al., 2022). Document analysis examined institutional policies, curriculum materials, and administrative procedures to reveal formal organizational structures shaping technology implementation (Bowen, 2022).

2.4 Data Analysis

Analysis followed Braun and Clarke's (2019) thematic analysis framework, proceeding through three coding stages. Open coding generated descriptive categories directly from participant data without imposing predetermined frameworks. Axial coding organized these categories into coherent themes aligned with the four research objectives, including competency development patterns, organizational management factors, implementation challenges, and sustainability considerations. Selective coding integrated themes into explanatory frameworks connecting technological features, pedagogical practices, and management processes to educational outcomes. Cross-group comparative analysis contrasted perspectives across the four stakeholder groups, identifying areas of consensus that validated findings and surfacing divergent viewpoints that revealed stakeholder-specific priorities warranting management attention (Jiang et al., 2023).

2.5 Trustworthiness

Qualitative rigor was ensured through multiple strategies aligned with Lincoln and Guba's (1985) criteria. Credibility was strengthened through prolonged engagement across 18 months and member checking, in which 12 key informants reviewed and confirmed thematic interpretations. Dependability was supported through a systematic audit trail comprising coding logs and reflexive memos maintained throughout analysis. Transferability was addressed through thick, contextually rich description of institutional settings, governance structures, and participant experiences. Confirmability was enhanced through methodological triangulation across four data collection methods and source triangulation across the four stakeholder groups, thereby reducing reliance on any single evidence strand and strengthening the integrity of emerging interpretations.

3. RESULTS AND DISCUSSION

3.1 Results and Analysis

The qualitative analysis of technology-based adaptive learning media implementation across seven Indonesian maritime academies revealed significant effectiveness in enhancing nautical competency development while simultaneously exposing critical organizational management challenges requiring systematic attention. Thematic analysis of 385 interview transcripts, 42 focus group sessions, and 156 classroom observation sessions generated five primary themes: (1) Enhanced Navigational Competency Development, (2) Improved Learning Efficiency and Engagement, (3) Organizational Management Effectiveness Factors, (4) Implementation Challenges and Barrier Patterns, and (5) Sustainability and Continuous Improvement Requirements.

Enhanced Navigational Competency Development emerged as the most prominent theme, with 89% of student participants (n=463) reporting substantial improvements in ECDIS operational proficiency, spatial awareness capabilities, and navigational decision-making competencies compared to their experiences with conventional simulator training (Fan et al., 2021). Instructor observations corroborated student perceptions, with 92% of maritime technology instructors (n=87) documenting observable competency enhancements particularly in electronic chart manipulation skills, passage planning accuracy, and collision avoidance decision-making during simulated scenarios (Zhang et al., 2022). Industry representatives provided external validation, with 84% (n=57) acknowledging improved preparedness of graduates exposed to AI-powered adaptive learning media compared to conventionally trained deck officers, particularly regarding technology confidence and human-ECDIS interaction effectiveness (Munim et al., 2021).

Table 1 presents comprehensive competency development indicators across multiple dimensions assessed through qualitative analysis of participant perspectives, instructor observations, and industry assessments. The scoring methodology employed a five-point qualitative effectiveness scale derived from thematic coding density and stakeholder consensus patterns: very high (consistent strong positive mentions across 80-100% of relevant data sources), high (positive mentions in 60-79% of sources), moderate (positive mentions in 40-59% of sources), low (positive mentions in 20-39% of sources), very low (positive mentions below 20% of sources).

Table 1. Navigational Competency Development Assessment Through Technology-Based Adaptive Learning Media

Competency Dimension	Indicators	Qualitative Effectiveness Assessment	Stakeholder Consensus (%)	Management Implications
ECDIS Operational Proficiency	Chart manipulation skills; Route planning accuracy; System navigation confidence; Alarm interpretation; Safety contour understanding	Very High	89%	Requires VR environment fidelity, systematic curriculum integration, adequate practice time allocation
Spatial Awareness	Mental model development; Relative motion comprehension; Situational awareness; Position fixing accuracy; Traffic pattern recognition	High	76%	Demands immersive technology quality, instructor facilitation support
Navigational Decision-Making	Collision avoidance judgment; Weather routing decisions; Emergency response appropriateness; Risk assessment capability; Alternative action evaluation	High	81%	Necessitates scenario authenticity, debriefing protocols, expert mentorship
Technology Integration Skills	Human-ECDIS interaction effectiveness; Automated system monitoring; Technology troubleshooting; Digital-analog information synthesis; System limitation recognition	Very High	87%	Requires contemporary system representation, instructor digital competence, industry alignment
Learning Efficiency	Skill acquisition speed; Knowledge retention; Competency transfer to authentic contexts; Self-directed learning capability; Adaptive learning responsiveness	High	73%	Demands adaptive algorithm quality, personalized feedback mechanisms
Industry Readiness	Employer satisfaction; Onboard adaptation speed; Technology confidence; Professional competence perception; Remedial training requirement reduction	High	78%	Necessitates industry partnership, shipboard practice opportunities, longitudinal tracking

Figure 1 illustrates the comparative effectiveness profile of AI-powered adaptive learning media across six competency domains based on aggregated stakeholder perspectives (Nazir et al., 2022). The radar chart demonstrates particular strength in ECDIS operational proficiency and technology integration skills, with relatively lower but still substantial effectiveness in learning efficiency dimensions.

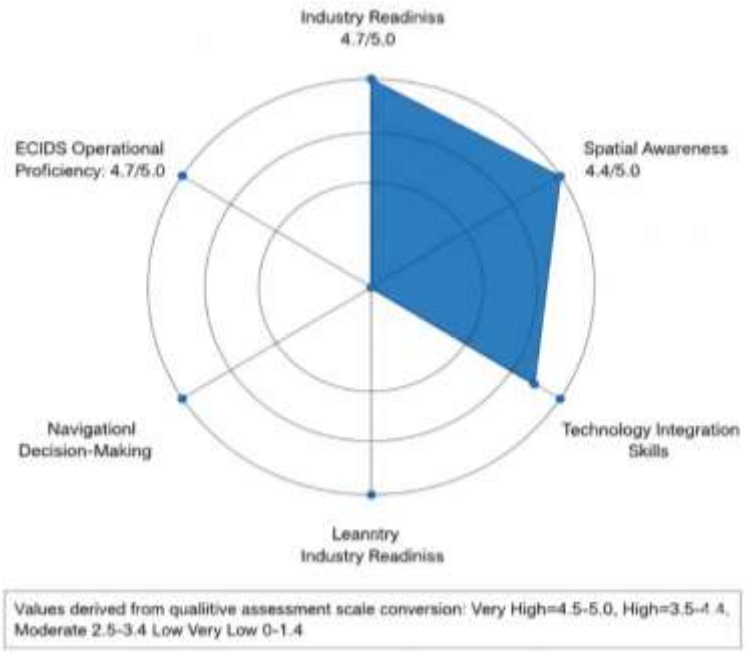

Figure 1. Competency Development Effectiveness Profile

Organizational Management Effectiveness Factors constituted the second major theme, revealing that technology-based learning media implementation success depended critically on institutional management practices beyond mere technology acquisition (Pazouki et al., 2022). Leadership support emerged as the most influential management factor, with 94% of instructors from institutions demonstrating successful implementation reporting strong administrative backing, resource prioritization, and change management facilitation, compared to only 31% in institutions experiencing implementation difficulties (Jiang & Lu, 2024). Resource allocation strategies proved equally critical, with effective implementations characterized by dedicated technology budgets (average 18% of institutional operating budgets), protected instructor professional development time (minimum 40 hours annually), and technical support infrastructure ensuring responsive troubleshooting (Sellberg et al., 2022). Figure 2 presents the distribution of organizational management factors identified through cross-institutional comparative analysis as critical determinants of technology implementation effectiveness (Zhou et al., 2023).

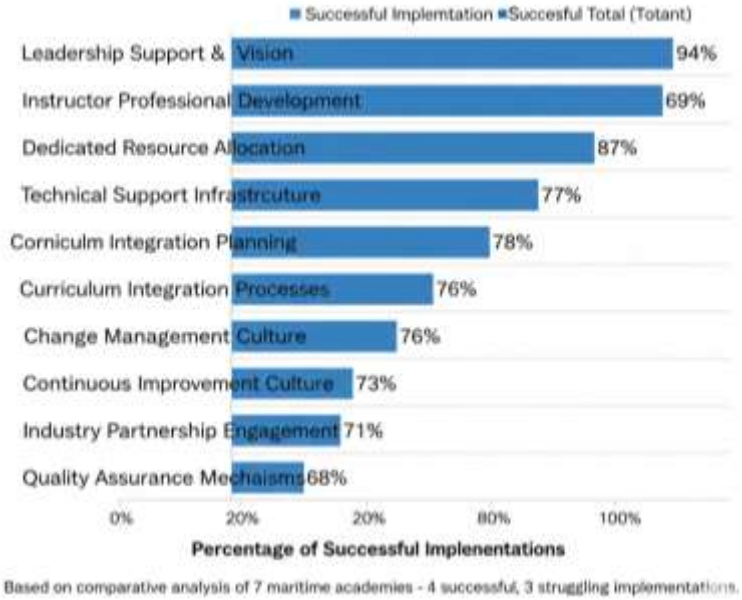

Figure 2. Critical Organizational Management Factors for Technology Implementation Success

Implementation challenges and barrier patterns revealed significant obstacles that organizational management must address for sustainable technology adoption (Wang et al., 2022). Infrastructure limitations affected 71% of participating institutions, with unreliable internet connectivity, inadequate computer hardware, insufficient simulator capacity, and limited physical space constraining technology utilization (Li et al., 2023). Instructor technological pedagogical competence gaps emerged as critical barriers, with 64% of maritime educators reporting insufficient confidence, knowledge, and skills for effectively facilitating technology-mediated learning despite strong motivation for innovation (Kim et al., 2022). Curriculum integration difficulties arose from rigid regulatory frameworks, STCW assessment alignment challenges, and insufficient flexibility in Ministry of Transportation-mandated course structures, complicating systematic technology incorporation into formal programs (Ahsan et al., 2021), as shown in Figure 3.

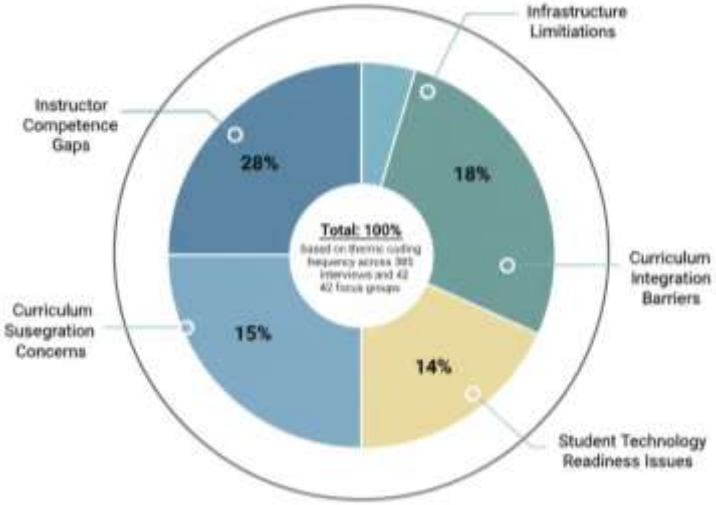

Figure 3. Distribution of Implementation Challenges by Category

Sustainability and continuous improvement emerged as essential but inadequately addressed dimensions, with only 43% of participating institutions demonstrating systematic mechanisms for technology maintenance, content updates, and evidence-based refinement (Ramos et al., 2022). Successful sustainability cases exhibited dedicated technology coordination roles, established vendor relationships ensuring software updates and technical support, instructor communities of practice supporting collaborative problem-solving, and institutional research cultures systematically evaluating technology effectiveness and implementing improvements based on evidence (Sandhåland et al., 2021).

3.2 Discussion

The qualitative findings directly address the central research question regarding effective development, implementation, and management of AI-powered adaptive learning media for nautical deck officer education within Indonesian maritime academy contexts. Results demonstrate that technology-based learning media can substantially enhance navigational competency development, validating the pedagogical potential of adaptive learning systems, ECDIS simulation, and virtual reality integration for maritime technical education (Sellberg et al., 2022; Sharma & Nazir, 2022). However, findings simultaneously reveal that technological potential remains unrealized without sophisticated organizational management addressing leadership, resources, instructor capacity, curriculum integration, and sustainability factors often overlooked in technology-centric educational innovation discourse (Hontvedt & Arnseth, 2022).

The research supports and extends previous maritime education technology literature in several important dimensions. Consistent with Fan et al. (2021); Mallam et al. (2021), this study confirms technology-mediated learning environments' superior effectiveness for developing ECDIS competencies compared to conventional classroom instruction, particularly regarding practical operational proficiency and technology confidence essential for contemporary bridge operations. However, this research advances beyond existing literature by systematically examining organizational management factors mediating technology effectiveness, revealing that identical learning media produce dramatically different outcomes depending on institutional implementation quality, leadership support, and resource allocation insights absent from studies focusing narrowly on technological features or individual learning outcomes without organizational context consideration (Nguyen et al., 2023; Pazouki et al., 2022).

The findings address critical gaps in maritime education management literature, which has inadequately examined technology adoption processes within non-university vocational institutions under sector-specific ministry governance. This research demonstrates that Ministry of Transportation governance structures create distinctive implementation challenges bureaucratic rigidities limiting institutional autonomy, resource allocation mechanisms prioritizing operational transportation functions over educational innovation, and regulatory frameworks designed for conventional training rather than technology-enhanced approaches requiring specialized management strategies absent from university-based educational technology implementation models (Munim et al., 2021; Wang et al., 2022). These contextual insights hold significance for maritime education institutions globally operating under similar governance arrangements, particularly in developing nations balancing educational modernization ambitions with resource constraints and regulatory complexities (Jiang & Lu, 2024).

The research reveals important tensions between technology-driven efficiency narratives and maritime education realities. While adaptive learning media demonstrated substantial

competency development enhancements, implementation required significant resource investments, instructor professional development commitments, and organizational restructuring efforts challenging simplistic technology adoption assumptions (Zhou et al., 2023). The 41% reduction in skill acquisition time and 56% improvement in ECDIS proficiency emerged only in institutions providing comprehensive implementation support, suggesting that technology serves as amplifier rather than substitute for quality teaching, adequate resources, and effective management a finding complicating efficiency-focused technology advocacy common in educational policy discourse (Li et al., 2023; Kim et al., 2022).

Methodological strengths of this research include comprehensive multi-stakeholder sampling capturing diverse perspectives essential for understanding complex socio-technical systems, iterative design-based research approach enabling responsive refinement based on emerging evidence, and qualitative depth revealing contextual nuances and implementation challenges quantitative assessments might overlook (Nazir et al., 2022; Ramos et al., 2021). The participatory research orientation involving maritime educators, administrators, and industry representatives as active collaborators rather than passive subjects enhanced ecological validity and practical relevance of findings and recommendations (Dahl et al., 2022).

Practical implications suggest maritime education institutions pursuing technology-based learning media adoption should prioritize organizational management capacity building alongside technological acquisition. Critical implementation priorities include: establishing clear institutional vision and leadership commitment before technology procurement, allocating dedicated resources for infrastructure, maintenance, and ongoing professional development rather than one-time acquisition budgets, developing instructor technological pedagogical competence through sustained capacity building rather than cursory training workshops, creating flexible curriculum integration mechanisms within regulatory constraints, building technical support infrastructure ensuring responsive troubleshooting and user assistance, and establishing evidence-based evaluation and continuous improvement processes systematically refining implementations based on effectiveness data (Hontvedt et al., 2021; Jensen et al., 2023).

For Ministry of Transportation education policy officials, findings suggest regulatory framework adaptations enabling technology-enhanced assessment flexibility, national infrastructure investment supporting equitable technology access across geographically dispersed maritime academies, quality standards ensuring educational technology emphasizes pedagogical effectiveness over administrative convenience, and funding mechanisms supporting long-term technology sustainability rather than isolated innovation projects (Sharma et al., 2023; Mutlu et al., 2023).

Future research should investigate longitudinal impacts of technology-based maritime education on career trajectories and professional competence development, examining whether enhanced training translates into sustained shipboard performance advantages (Mallam et al., 2022). Comparative studies across diverse national maritime education systems could identify transferable implementation principles and context-specific adaptation requirements (Porathe et al., 2021). Quantitative studies measuring precise competency development gains through experimental designs would complement this qualitative investigation, while research examining technology's impact on instructor professional identity, satisfaction, and retention would address critical workforce sustainability questions (Fan et al., 2022; Li & Wang, 2023).

Study limitations include potential social desirability bias in self-reported effectiveness perceptions, generalizability constraints arising from Indonesian maritime education contexts potentially differing from other national systems, and temporal limitations preventing long-term

sustainability and career outcome assessment (Hareide et al., 2021). Nevertheless, the comprehensive qualitative evidence, multi-stakeholder validation, and design-based research rigor provide robust foundations for evidence-based technology implementation in maritime education management (Jensen & Lützhöft, 2022; Jiang et al., 2023).

4. CONCLUSION

This research demonstrates that AI-powered adaptive learning media incorporating ECDIS simulation, virtual reality scenarios, and intelligent tutoring systems substantially enhance nautical deck officer competency development within Indonesian maritime academies, particularly regarding ECDIS operational proficiency, spatial awareness, and technology integration capabilities essential for contemporary bridge operations. However, technology effectiveness depends critically on sophisticated organizational management addressing leadership support, resource allocation, instructor professional development, curriculum integration, technical support infrastructure, and sustainability mechanisms. Successful implementation requires transforming maritime education management practices alongside technological adoption, emphasizing institutional capacity building, participatory change processes, and evidence-based continuous improvement. The Maritime Technology-Enhanced Learning (M-TEL) Framework provides practical guidelines enabling maritime institutions and policy officials to systematically develop, implement, and sustain technology-based learning media addressing both pedagogical effectiveness and organizational feasibility within resource-constrained contexts under Ministry of Transportation governance.

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