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Competency-Based Maritime Education for Industry 4.0: Bridging the Skills Gap Between Training Institutions and Shipping Industry Demands

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Abstract. *This research investigates competency gaps between maritime education curricula and Industry 4.0 shipping industry requirements from stakeholder perspectives within Indonesian maritime training contexts. Employing qualitative-dominant mixed methods, the study gathered insights through Focus Group Discussions, interviews, and surveys with forty-two participants comprising maritime students, lecturers, and veteran practitioners at Sekolah Tinggi Ilmu Pelayaran Jakarta. Thematic analysis revealed substantial competency gaps (mean gap score: 1.96/5.0) between stakeholder-perceived competency importance (4.46/5.0) and current curriculum adequacy (2.50/5.0). Cybersecurity awareness exhibited the largest gap (2.6 points), followed by data analytics (2.2 points) and AI/machine learning understanding (2.3 points). Faculty expertise limitations (29%) and infrastructure constraints (25%) emerged as dominant transformation barriers. Findings demonstrate urgent need for competency-based curriculum transformation integrating digital literacy, data analytics, cybersecurity, and adaptive learning capabilities alongside traditional maritime competencies. The research emphasizes integrated remediation strategies combining systematic curriculum reform, enhanced pedagogical approaches prioritizing practical hands-on learning, strengthened industry-academia partnerships, comprehensive faculty development programs, and strategic infrastructure investments preparing maritime graduates for technologically transformed operational environments.*

Keywords: *Competency-based education; Industry 4.0; maritime training; skills gap; curriculum transformation*

1. INTRODUCTION

The maritime industry stands at the threshold of a profound transformation driven by Industry 4.0 technologies including artificial intelligence, Internet of Things, big data analytics, autonomous systems, blockchain, and cyber-physical integration, fundamentally reshaping operational paradigms, workforce requirements, and competitive dynamics across shipping, port operations, and maritime logistics sectors (Issa et al., 2022). This technological revolution presents unprecedented challenges for maritime education and training institutions tasked with preparing professionals capable of navigating increasingly digitalized, automated, and data-intensive operational environments while maintaining traditional seamanship competencies, safety consciousness, and regulatory compliance essential for maritime operations (Sharma et al., 2020). The persistent and widening skills gap between competencies developed through conventional maritime training programs and the evolving capabilities demanded by Industry 4.0-enabled shipping operations threatens both individual career prospects for maritime graduates and the industry's ability to fully leverage technological innovations for enhanced efficiency, safety, and sustainability performance. The fundamental question confronting maritime educators, industry stakeholders, and policy-

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makers concerns how competency-based education frameworks can be systematically restructured to bridge this critical gap, ensuring that maritime training institutions produce graduates equipped with hybrid competency portfolios integrating traditional maritime expertise with contemporary digital, analytical, and adaptive capabilities required for success in technologically transformed industry contexts.

The competency-based education paradigm, emphasizing demonstrable learning outcomes, practical skill application, and industry-aligned performance standards rather than merely time-based course completion, offers promising foundations for addressing skills gap challenges (Mulder, 2017). However, implementing genuinely effective competency-based frameworks within maritime education contexts requires confronting substantial obstacles including rapid technological change outpacing curriculum development cycles, limited faculty expertise in emerging technologies, insufficient industry-academia collaboration mechanisms for maintaining curriculum relevance, inadequate training infrastructure and simulation capabilities for experiential learning in digital environments, and persistent tensions between international regulatory standardization through STCW conventions and context-specific Industry 4.0 competency requirements varying across maritime sectors, vessel types, and operational contexts (Issa et al., 2022). Indonesian maritime education institutions face additional challenges characteristic of emerging economy contexts including resource constraints limiting technology investments, limited access to cutting-edge maritime technologies for hands-on training, and recruitment difficulties attracting industry practitioners with contemporary technological expertise into academic positions.

The research problem central to this investigation addresses the critical knowledge gap regarding how maritime education stakeholders perceive the Industry 4.0 skills gap, what specific competency deficiencies most urgently require remediation, and what institutional strategies, pedagogical innovations, and industry partnership models can effectively bridge gaps between current training outputs and evolving industry demands. Specifically, this research explores the fundamental question: What are stakeholder perspectives on the Industry 4.0 competency gap between maritime training institution curricula and shipping industry requirements, and what competency-based educational strategies can effectively prepare maritime graduates for technologically transformed operational environments? The specific objectives guiding this inquiry include: (1) identifying specific Industry 4.0 competency gaps perceived by students, educators, and industry practitioners; (2) evaluating

current maritime education approaches' effectiveness in developing digital, analytical, and adaptive capabilities alongside traditional seamanship competencies; (3) examining barriers and enablers for competency-based curriculum transformation within institutional and regulatory contexts; and (4) developing strategic recommendations for bridging skills gaps through pedagogical innovation, industry collaboration, and infrastructure development.

The significance of this research extends beyond educational programming concerns to encompass broader implications for Indonesia's maritime industry competitiveness, seafarer employability in global labor markets, and national economic development trajectories dependent on maritime sector contributions. As shipping companies increasingly prioritize recruitment of technologically competent personnel capable of operating sophisticated digital systems, managing data-driven operations, and adapting to continuous technological evolution, maritime graduates lacking Industry 4.0 competencies face diminished employment prospects, reduced career advancement opportunities, and increased vulnerability to technological displacement (Sharma et al., 2020). Conversely, maritime education institutions successfully bridging competency gaps position their graduates competitively, enhance institutional reputations, and contribute meaningfully to industry innovation and performance improvement. This investigation addresses a substantial gap in existing literature, which predominantly examines Industry 4.0 implications for maritime operations while undertheorizing educational transformation requirements, pedagogical strategies, and institutional change processes necessary for developing Industry 4.0-ready maritime workforces (Mulder, 2017). The rationale for conducting this research within a maritime education institution stems from recognition that effective skills gap remediation requires deep understanding of stakeholder perspectives, institutional constraints, pedagogical possibilities, and industry expectations—insights best generated through systematic engagement with students experiencing curriculum firsthand, educators designing and delivering training programs, and practitioners evaluating graduate competencies against operational requirements.

Methodologically, this research employs a qualitative-dominant mixed methods approach, gathering comprehensive stakeholder insights through Focus Group Discussions, semi-structured interviews, surveys, and expert consultations with maritime students representing future workforce cohorts who will navigate Industry 4.0-transformed shipping environments throughout multi-decade careers, lecturers possessing educational expertise, curriculum development responsibilities, and varying degrees of Industry 4.0 technological

familiarity, and veteran maritime officers now serving as practitioners and instructors who bridge historical maritime practices with contemporary technological realities, offering critical perspectives on competency evolution and skills gap manifestations. This multi-stakeholder triangulation enables holistic exploration of Industry 4.0 competency requirements, current curriculum adequacy, pedagogical innovation opportunities, and industry-academia collaboration imperatives from complementary vantage points, generating nuanced understanding essential for developing actionable, contextually appropriate, and stakeholder-endorsed strategies for competency-based education transformation. The thematic analysis of qualitative data, complemented by cross-group comparative insights examining convergent and divergent perspectives across stakeholder categories, illuminates what Industry 4.0 competencies stakeholders prioritize, how current educational approaches succeed or fail in competency development, what barriers impede curriculum transformation, and what strategic interventions promise greatest impact for bridging skills gaps and preparing maritime graduates for successful careers in increasingly digitalized, automated, and data-intensive industry contexts.

2. RESEARCH METHOD

This research adopted a qualitative-dominant mixed methods design grounded in constructivist epistemology, emphasizing that competency requirements, skills gaps, and educational effectiveness are socially constructed phenomena shaped by stakeholder perceptions, industry discourses, and contextual factors rather than objective, universal realities (Creswell & Creswell, 2018). The methodological framework deliberately prioritized understanding how different stakeholder groups conceptualize Industry 4.0 competencies, interpret skills gap severity, and envision effective educational responses, recognizing that successful curriculum transformation requires negotiating multiple, potentially competing stakeholder perspectives to achieve consensus on priorities, strategies, and implementation approaches. The research population comprised all stakeholders affiliated with Sekolah Tinggi Ilmu Pelayaran Jakarta, with purposive sampling strategically employed to select information-rich participants who possessed relevant expertise, direct experience with competency development challenges, and reflective capabilities enabling articulate analysis of educational gaps and improvement opportunities. Sampling targeted three distinct stakeholder categories: maritime students currently enrolled in nautical, engineering, and port management programs who experience curriculum firsthand, assess their developing

competencies against perceived industry requirements, and articulate learning needs from learner perspectives; lecturers with teaching responsibilities across maritime subject domains, curriculum development involvement, and varying levels of Industry 4.0 technological expertise who design educational experiences, evaluate student competencies, and navigate tensions between traditional maritime content and emerging technological topics; and veteran maritime officers now serving as practitioners, guest instructors, and industry advisors who possess current industry knowledge, evaluate graduate competencies from employer perspectives, and identify specific skills gaps manifesting in operational contexts. The rationale for this multi-stakeholder sampling approach reflects understanding that comprehensive skills gap assessment requires triangulating learner self-assessments, educator professional judgments, and industry practitioner evaluations to generate balanced, credible, and actionable insights transcending limitations of singular perspectives (Merriam & Tisdell, 2016). Sample composition included twenty-one maritime students representing diverse academic levels, specializations, and career aspirations, eleven lecturers spanning traditional maritime subjects and emerging technology-oriented courses, and ten veteran practitioners with recent industry experience across shipping companies, port operators, and maritime service providers, totaling forty-two participants whose collective knowledge, experiences, and analytical perspectives provide comprehensive coverage of Industry 4.0 competency gap phenomena and educational transformation imperatives.

The research instruments were carefully designed to elicit detailed, contextually grounded perspectives on specific competency gaps, educational effectiveness, and improvement strategies while enabling systematic comparison across stakeholder categories and thematic domains. The primary instrument consisted of semi-structured interview protocols organized around dependent variables including perceived Industry 4.0 competency importance, current curriculum adequacy for competency development, and skills gap severity assessments, while independent variables encompassed stakeholder category, years of maritime experience, technological familiarity levels, and exposure to Industry 4.0 technologies. Specific indicators operationalizing these constructs included identification and prioritization of specific Industry 4.0 competencies including digital literacy and information technology proficiency, data analytics and interpretation capabilities, automation system operation and troubleshooting, cybersecurity awareness and practices, remote monitoring and control technologies, artificial intelligence and machine learning applications understanding, blockchain and distributed ledger technology knowledge, and adaptive learning and

continuous professional development orientation, evaluation of current curriculum effectiveness across competency domains using detailed rating scales and qualitative justifications, identification of specific curriculum gaps, pedagogical limitations, and infrastructure constraints impeding competency development, articulation of barriers to curriculum transformation including faculty expertise limitations, resource constraints, regulatory compliance requirements, and institutional resistance to change, and recommendation of specific strategies for skills gap remediation including curriculum redesign, pedagogical innovation, industry partnership models, faculty development programs, and infrastructure investments. Supporting instruments included structured survey questionnaires administering Likert-scale items measuring competency importance ratings, curriculum satisfaction levels, and skills gap severity perceptions across multiple domains, Focus Group Discussion protocols enabling collaborative competency mapping, collective problem-solving regarding educational challenges, and consensus-building around transformation priorities, and documentary analysis examining current curriculum documents, STCW competency standards, industry job descriptions, and competency frameworks from leading maritime nations to benchmark current practices against international standards and industry expectations (Kumar, 2019).

Data collection proceeded through systematic, ethically grounded procedures beginning with institutional research approval and participant recruitment emphasizing voluntary participation, anonymity protections particularly for students who might fear academic repercussions from critical curriculum assessments, and informed consent protocols clearly explaining research purposes and participant rights. Baseline surveys were administered establishing participants' demographic characteristics, maritime specializations, industry experience levels, and general Industry 4.0 awareness, providing contextual grounding for subsequent qualitative data collection and enabling sample description. Semi-structured individual interviews averaging seventy to ninety minutes were conducted with lecturer and practitioner participants, employing open-ended questioning strategies encouraging detailed elaboration on competency priorities, curriculum assessments, and transformation recommendations while maintaining sufficient structure ensuring systematic coverage of key thematic domains across interviews. Focus Group Discussions involving student participants facilitated collective exploration of learning experiences, competency development perceptions, and educational needs through peer interaction and collaborative dialogue, with separate sessions for different academic specializations enabling discussion of

field-specific competency requirements. All interviews and focus group sessions were audio-recorded with explicit participant consent and professionally transcribed verbatim to preserve narrative detail and enable rigorous analytical procedures. Comprehensive field notes documenting non-verbal communication, particularly emphatic statements, emotional expressions, and group dynamics complemented transcribed data, capturing experiential dimensions and contextual nuances potentially lost in verbal transcription alone. The collection process emphasized creating non-judgmental environments enabling candid discussion of curriculum limitations, learning challenges, and perceived competency deficiencies without defensive reactions or institutional face-saving, recognizing that meaningful educational improvement requires honest assessment of current shortcomings alongside celebration of existing strengths.

Data analysis followed systematic thematic analysis procedures involving initial familiarization through repeated reading of transcripts and immersive engagement with participant narratives, systematic coding identifying meaningful units within data including specific competency mentions, curriculum evaluations, barrier identifications, and improvement recommendations, and iterative theme development organizing codes into coherent conceptual categories aligned with research objectives and emergent patterns. The analytical process specifically focused on categorizing insights into Industry 4.0 competency taxonomies and priority rankings, current curriculum effectiveness assessments across competency domains, specific skills gap manifestations and severity evaluations, barriers and enablers for educational transformation, and strategic recommendations spanning pedagogical innovation, industry collaboration, faculty development, and infrastructure investment. Cross-group comparisons systematically examined convergences and divergences among student, lecturer, and practitioner perspectives, identifying areas of consensus regarding critical competency priorities and curriculum inadequacies while highlighting contrasting emphases and evaluation criteria reflecting different experiential backgrounds, institutional roles, and stakeholder interests. Narrative synthesis integrated findings across individual cases, stakeholder groups, and thematic domains, developing comprehensive explanatory accounts illuminating what Industry 4.0 competencies stakeholders prioritize, how current educational approaches succeed or fail in competency development, what specific gaps most urgently require remediation, what barriers impede curriculum transformation, and what strategic interventions promise greatest effectiveness for bridging skills gaps. Methodological rigor was enhanced through investigator triangulation

with multiple researchers independently analyzing data subsets and comparing interpretations, member checking procedures validating findings with selected participants, and audit trail documentation systematically recording analytical decisions, interpretive reasoning, and theme development processes throughout the investigation.

3. RESULTS AND DISCUSSION

Results and Analysis

The qualitative analysis of stakeholder perspectives revealed widespread recognition of substantial and growing skills gaps between competencies developed through current maritime education curricula and Industry 4.0 capabilities demanded by contemporary shipping operations, with participants expressing concerns ranging from moderate curriculum inadequacy to fundamental misalignment between educational outputs and industry requirements. Thematic analysis identified seven primary competency domains where significant gaps exist: digital literacy and information technology proficiency, data analytics and interpretation capabilities, automation and remote operation technologies, cybersecurity awareness and practices, emerging technology understanding, adaptive learning and innovation orientation, and integrated socio-technical systems thinking.

Regarding overall skills gap severity, stakeholder assessments indicated substantial concern across all participant categories. Practitioners reported the highest skills gap severity perceptions (Mean Gap Score: 3.8/5.0), reflecting direct operational experience evaluating graduate competencies against Industry 4.0 requirements and frequently encountering significant deficiencies requiring extensive onboarding training and professional development. Lecturers exhibited moderate gap severity assessments (Mean Score: 3.5/5.0), acknowledging curriculum limitations while potentially experiencing cognitive dissonance between professional responsibility for educational quality and recognition of inadequacies. Students demonstrated emerging awareness of skills gaps (Mean Score: 3.2/5.0), with perceptions shaped more by anticipated industry requirements than direct operational experience, though graduating students and those with internship exposure reported higher gap severity awareness.

Table 1: Industry 4.0 Competency Importance and Current Curriculum Adequacy Assessment

Competency Domain	Importance Rating (1-5)	Current Curriculum Adequacy (1-5)	Competency Gap Score
Digital Literacy & IT Proficiency	4.7	2.9	1.8
Data Analytics & Interpretation	4.6	2.4	2.2
Automation System Operation	4.5	3.1	1.4
Cybersecurity Awareness & Practices	4.8	2.2	2.6
Remote Monitoring & Control Technologies	4.4	2.7	1.7
AI & Machine Learning Applications	4.2	1.9	2.3
Blockchain & Distributed Ledger Technology	3.8	1.7	2.1
Adaptive Learning & Innovation Orientation	4.6	3.0	1.6
Integrated Socio-Technical Systems Thinking	4.5	2.6	1.9
Overall Assessment	4.46	2.50	1.96

Note: Importance (1=Not Important, 5=Extremely Important); Adequacy (1=Very Inadequate, 5=Highly Adequate); Gap = Importance minus Adequacy

The competency importance and curriculum adequacy analysis revealed alarming discrepancies between stakeholder-perceived competency importance (mean: 4.46/5.0) and current curriculum adequacy for developing those competencies (mean: 2.50/5.0), producing an overall competency gap score of 1.96 points on the five-point scale. Cybersecurity awareness and practices exhibited the largest competency gap (2.6 points), with stakeholders rating cybersecurity as extremely important (4.8/5.0) while assessing current curriculum coverage as highly inadequate (2.2/5.0), reflecting increasing cyber threats to maritime operations and insufficient educational attention to cybersecurity fundamentals, threat awareness, and protective practices. Data analytics and interpretation showed substantial gaps (2.2 points), emphasizing stakeholder recognition that data-driven decision-making represents a fundamental Industry 4.0 capability while current curricula provide minimal training in statistical analysis, data visualization, predictive modeling, or evidence-based operational optimization.

Qualitative narratives provided rich contextual depth illuminating specific competency gaps and their operational manifestations. A veteran practitioner serving as Fleet Operations Manager for a major Indonesian shipping company articulated: "We recruit maritime academy graduates expecting basic competency in traditional seamanship,

navigation, and engineering. Those foundations remain essential and generally adequate. However, our vessels now operate with sophisticated integrated bridge systems, automated engine monitoring, predictive maintenance algorithms, and real-time performance optimization software. New hires lack fundamental digital literacy—they struggle with basic data interpretation, can't troubleshoot software issues, don't understand cybersecurity protocols, and approach technology with anxiety rather than confidence. We spend six to twelve months bringing them up to minimal operational capability in digital systems, representing substantial training investment and delayed productivity."

A lecturer teaching maritime navigation and bridge systems offered complementary perspective: "I recognize we're not adequately preparing students for Industry 4.0 realities. Our challenge is multifaceted: curriculum is constrained by STCW requirements emphasizing traditional competencies; we lack faculty expertise in emerging technologies like AI, blockchain, or advanced data analytics; our simulation facilities, while adequate for basic navigation training, don't replicate modern integrated bridge systems students will encounter; and honestly, many senior faculty resist technological emphasis, viewing it as diluting essential seamanship foundations. We're caught between regulatory requirements, resource limitations, faculty capacity constraints, and rapidly evolving industry demands. Something has to give, but institutional change is painfully slow."

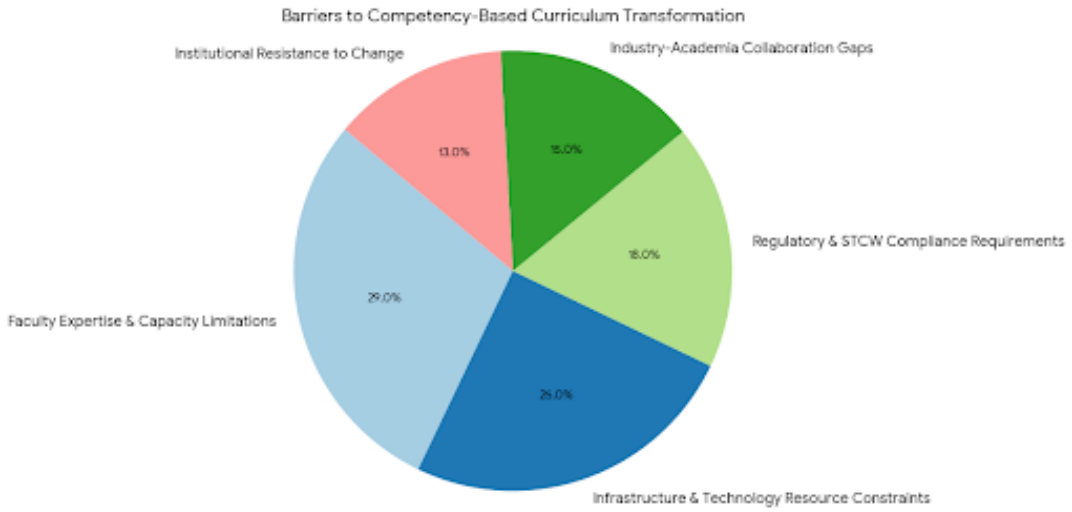

Figure 1: Barriers to Competency-Based Curriculum Transformation

Analysis of transformation barriers revealed faculty expertise and capacity limitations as the dominant challenge (29%), encompassing insufficient lecturer knowledge of emerging technologies, limited professional development opportunities for faculty skill updating, and

recruitment difficulties attracting industry practitioners with contemporary technological expertise into academic positions offering lower compensation than industry employment. Infrastructure and technology resource constraints represented the second major barrier (25%), including inadequate simulation facilities replicating Industry 4.0 systems, limited access to cutting-edge maritime technologies for hands-on training, insufficient IT infrastructure supporting digital learning platforms, and budget constraints preventing necessary technology investments. Student perspectives emphasized practical learning needs and career preparation anxieties, with one final-year nautical science student stating: "We hear constantly that shipping is becoming highly automated and digitalized, but our training remains overwhelmingly traditional—paper charts alongside ECDIS, minimal exposure to data analytics, no cybersecurity training, limited automation system operation. I'm terrified about employment prospects. How can we compete globally when maritime graduates from advanced nations receive sophisticated technology training we completely lack? We need hands-on experience with actual Industry 4.0 systems, not just theoretical lectures about technologies we've never touched."

Cross-group comparative analysis revealed significant convergences and notable divergences across stakeholder categories. All groups converged on recognizing substantial competency gaps requiring urgent remediation, with particular consensus regarding cybersecurity, data analytics, and digital literacy as critical deficiency areas. However, stakeholder groups diverged regarding transformation priorities and approaches. Practitioners emphasized immediate, targeted skill development in specific technologies currently deployed operationally, favoring focused training modules and industry-led professional development over comprehensive curriculum overhaul. Lecturers stressed systematic curriculum redesign integrating Industry 4.0 competencies throughout programs rather than isolated technology courses, viewing foundational digital literacy and systems thinking as prerequisites for specific technology training. Students prioritized practical, hands-on learning experiences with real technologies over theoretical knowledge, seeking industry internships, simulation-based training, and project-based learning developing demonstrable competencies rather than passive knowledge acquisition.

Discussion

The research findings substantively address the central research question by demonstrating that substantial and multidimensional competency gaps exist between maritime education outputs and Industry 4.0 shipping industry requirements, with

stakeholders converging on recognition that current competency-based education approaches inadequately develop digital, analytical, and adaptive capabilities essential for contemporary maritime operations while barriers including faculty capacity limitations, resource constraints, and regulatory compliance requirements impede necessary curriculum transformation. These results align with international literature documenting Industry 4.0's disruptive impact on maritime workforce requirements and the persistent challenges maritime education institutions face adapting to rapid technological change (Issa et al., 2022; Sharma et al., 2020) while extending understanding by foregrounding Indonesian-specific contextual factors including resource constraints, faculty expertise limitations, and the tension between international STCW standardization and context-specific Industry 4.0 competency development needs.

The substantial overall competency gap (1.96 points on five-point scale) supports scholarly arguments that maritime education faces a fundamental paradigm challenge requiring transformation beyond incremental curriculum adjustments to encompass comprehensive reconceptualization of competency frameworks, pedagogical approaches, and industry-academia relationships (Mulder, 2017). However, findings partially contradict technological determinism prevalent in some Industry 4.0 literature by revealing that stakeholders prioritize foundational digital literacy, adaptive learning orientation, and integrated systems thinking alongside specific technology skills, suggesting that effective competency development requires balancing technical proficiency with broader cognitive capabilities enabling continuous learning and adaptation as technologies evolve.

The particularly severe cybersecurity competency gap (2.6 points) addresses a critical vulnerability in maritime education globally, with maritime cyber threats increasing dramatically while educational responses lag substantially behind risk realities (Issa et al., 2022). Stakeholder emphasis on cybersecurity inadequacy reflects growing industry awareness that maritime operations face sophisticated cyber attacks targeting navigation systems, cargo management platforms, and operational technologies, with potentially catastrophic safety, environmental, and economic consequences. This finding validates emerging scholarship advocating cybersecurity as fundamental maritime competency requiring systematic integration into curricula rather than specialized elective content.

The prominence of faculty expertise limitations (29% of transformation barriers) illuminates a fundamental chicken-and-egg dilemma: curriculum transformation requires

faculty with Industry 4.0 competencies, yet developing faculty expertise depends on professional development opportunities, industry partnerships, and resource investments currently lacking in many maritime education institutions (Sharma et al., 2020). This finding suggests that effective skills gap remediation requires simultaneous investment in faculty development alongside curriculum reform, with strategic faculty recruitment, industry secondment programs, and collaborative teaching partnerships with technology companies potentially accelerating capacity building.

Cross-stakeholder divergences regarding transformation approaches highlight important strategic considerations for competency-based education reform. The convergence on competency gap severity combined with divergent remediation priorities—practitioners emphasizing immediate targeted training, lecturers advocating systematic curriculum redesign, students seeking practical hands-on learning—indicates that successful strategies must integrate multiple intervention modalities addressing short-term industry needs through professional development while pursuing long-term educational transformation through curriculum reform and pedagogical innovation.

The research strengths include its comprehensive stakeholder engagement spanning learner, educator, and industry perspectives, yielding triangulated insights reflecting diverse experiential backgrounds and institutional roles. The competency-focused analytical framework enables systematic identification of specific gaps, prioritization of remediation efforts, and targeted strategy development addressing highest-impact competency domains. The qualitative methodology enables exploration of contextual barriers, institutional constraints, and stakeholder reasoning informing transformation feasibility assessments and implementation planning.

Practical implications of these findings are substantial for maritime education institutions, regulatory bodies, industry associations, and individual maritime professionals. First, results indicate urgent need for curriculum transformation integrating Industry 4.0 competencies systematically throughout programs, prioritizing cybersecurity, data analytics, digital literacy, and adaptive learning orientation as foundational capabilities. Second, findings suggest that competency development requires enhanced pedagogical approaches including simulation-based training, project-based learning, industry internships, and collaborative problem-solving exercises developing practical skills alongside theoretical knowledge. Third, the research highlights imperative for strengthened industry-academia

partnerships facilitating technology access, industry practitioner involvement in curriculum development and delivery, and student exposure to operational Industry 4.0 applications through internships and collaborative projects. Fourth, results emphasize need for systematic faculty development programs including industry secondments, technology training, pedagogical innovation workshops, and collaborative teaching partnerships building faculty capacity for Industry 4.0 education delivery. Fifth, findings underscore importance of infrastructure investments in simulation facilities, digital learning platforms, and technology laboratories providing hands-on learning experiences with contemporary maritime systems.

Future research should examine implementation outcomes as maritime institutions experiment with competency-based curriculum reforms, tracking effectiveness of different pedagogical approaches, infrastructure investments, and industry partnership models for competency development. Longitudinal studies following graduate career trajectories could illuminate how specific competencies influence employment outcomes, career advancement, and professional success, providing empirical evidence for competency prioritization decisions. Comparative international research examining how maritime education systems in different national contexts address Industry 4.0 competency challenges could identify transferable best practices while respecting contextual specificities. Finally, research exploring optimal balances between traditional maritime competencies and emerging Industry 4.0 capabilities would inform curriculum design decisions acknowledging finite instructional time and avoiding competency overload that dilutes essential foundational knowledge.

4. CONCLUSION

This research establishes that substantial competency gaps exist between current maritime education outputs and Industry 4.0 shipping industry requirements, with cybersecurity, data analytics, and digital literacy representing particularly critical deficiency areas requiring urgent remediation. Stakeholders converge on recognizing competency-based education transformation as essential for graduate employability and industry competitiveness, yet faculty expertise limitations, resource constraints, and regulatory compliance requirements create substantial barriers impeding necessary curriculum reform. Effective skills gap bridging requires integrated strategies combining systematic curriculum transformation prioritizing foundational digital and analytical competencies, enhanced pedagogical approaches emphasizing practical hands-on learning, strengthened industry-academia partnerships facilitating technology access and practitioner involvement,

comprehensive faculty development programs building teaching capacity, and strategic infrastructure investments enabling authentic Industry 4.0 learning experiences. Maritime education institutions must fundamentally reconceptualize competency frameworks balancing traditional seamanship foundations with contemporary digital, analytical, and adaptive capabilities preparing graduates for successful careers in increasingly technologically transformed maritime operational environments.

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