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# Digital Simulation-Based Learning and Maritime Workforce Readiness: Moderating Roles of Stowage Competence and Technological Adaptability

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ABSTRAK

Work readiness in maritime higher education has become a socio-economic concern because the competitiveness of marine and fisheries logistics increasingly depends on human capital that can operate safely, efficiently, and adaptively in a digital environment. This study examines the effect of digital simulation-based learning on students' work readiness and tests the moderating roles of stowage competence and technological adaptability. The study used a quantitative explanatory design with a cross-sectional survey of 400 students from Politeknik Pelayaran Barombong and Politeknik Ilmu Pelayaran Makassar. Data were collected through a structured Likert-scale questionnaire and analyzed using Structural Equation Modeling–Partial Least Squares (SEM-PLS). The results show that digital simulation-based learning has a positive and significant effect on work readiness, with a direct path coefficient of 0.768. The structural model explains 85.3% of the variance in work readiness ($R^2$ = 0.853). Stowage competence strongly strengthens the relationship between digital simulation-based learning and work readiness ($f^2$ = 0.989), while technological adaptability also acts as a significant moderator with a coefficient of 0.217, t-statistic of 6.564, p-value of 0.000, and $f^2$ of 0.178. These findings indicate that the value of simulation does not lie only in pedagogy, but also in its contribution to the formation of maritime logistics human capital that is relevant to operational efficiency, workforce quality, and the modernization of marine and fisheries-related supply chains. The study recommends strengthening simulator-based training, work-process-oriented stowage instruction, and digital adaptability support within vocational maritime curricula.

**Keyword: digital simulation-based learning; maritime workforce readiness; stowage competence; technological adaptability; maritime logistics; socio-economic development**

## INTRODUCTION

The transformation of marine and fisheries value chains increasingly depends on the quality of maritime human resources. Port operations, cargo handling, warehousing, vessel support services, and fishery product distribution now require workers who can combine operational discipline with digital problem-solving capacity. In this context, work readiness is not merely an educational outcome, but a socio-economic issue because workforce quality affects service efficiency, logistics costs, employment absorption, and the competitiveness of marine and fisheries-related businesses. Studies on work readiness and graduate employability emphasise that higher education institutions are under growing pressure to align learning outcomes with labour-market needs and practical job demands, especially in sectors where safety and operational reliability have direct welfare implications (Orr et al., 2023; Peersia et al., 2024; Massi et al., 2026).

Digital simulation-based learning offers a promising approach for maritime education because it enables repeated practice, immediate feedback, and the safe reproduction of high-risk operational scenarios. In nautical and maritime settings, simulation helps students develop procedural understanding before entering real operational environments, while immersive and game-based learning models can improve engagement and situated decision-making (Pruyn, 2024; Sellberg & Giskeødegård, 2025; Christopoulos & Stylios, 2024; Song & Lai, 2025). However, the contribution of simulation should not be assessed only from a pedagogical perspective. For sectors connected to marine transport and fisheries logistics, simulation can also be interpreted as a strategic investment in human capital that promotes more efficient cargo handling, safer operations, and better adaptation to the digitalisation of supply chains (Turbaningsih et al., 2022; Nugraha et al., 2025a).

The socio-economic relevance of this issue is particularly strong in Indonesia, where maritime connectivity and fisheries distribution still face efficiency constraints. The archipelagic geography creates a structural demand for efficient sea-based logistics, and the fisheries and marine-products sector contributes significantly to employment and household income, especially in coastal and small-island regions. Competent graduates are

needed not only by shipping services but also by warehousing, port handling, and cold-chain-related operations that support the movement of marine and fishery products. From this perspective, work readiness among maritime students contributes to broader development goals, including labour productivity, reduced operational errors, and improved service quality in maritime logistics (Misas et al., 2024 Rodrigues et al., 2025; Zhu et al., 2026). The role of vocational education is therefore closely linked to social and institutional agendas in the marine economy, especially when educational innovation can support employability and operational resilience.

Prior research suggests that simulation-based learning is more effective when students possess supporting competencies and the confidence to use technology in changing work contexts. Stowage competence is important because it connects simulation experience with practical understanding of cargo placement, safety, documentation, and spatial efficiency. In marine and fisheries logistics, such competence has implications for loading accuracy, product protection, and the reduction of handling inefficiencies, all of which are economically meaningful for a sector characterised by narrow margins and time-sensitive perishable cargoes (Lagorio et al., 2025). At the same time, technological adaptability matters because students who can quickly learn new digital systems are more likely to benefit from simulation platforms and digital work processes (Wang et al., 2024; Ndibalema, 2025; Sutrisno et al., 2025). This adaptability is increasingly relevant as maritime operations adopt more data-driven and automated systems, including remote monitoring, digital twins, and AI-assisted decision-support tools.

Work readiness in maritime vocational education, however, cannot be reduced to technical skill alone. Recent evidence from Indonesia shows that safety mindset and operational discipline remain critical determinants of workforce quality, particularly in high-risk maritime settings (Uddin & Siska, 2026). Work readiness therefore comprises a bundle of cognitive, affective, and behavioural attributes that enable graduates to perform competently under uncertainty. This is consistent with the broader socio-economic view that human capital quality is shaped jointly by instructional design, applied competence, and adaptive capacity to technology (Kholifah et al., 2025; Otermans et al., 2025). Based on the framing above, this study aims to: (1) analyse the effect of digital simulation-based learning on students' work readiness in maritime higher education; (2) examine the role of stowage competence and technological adaptability in strengthening that relationship as moderating variables; and (3) discuss the socio-economic and policy implications of the findings for maritime and marine-fisheries human resource development in Indonesia. The novelty of this study lies not in the introduction of new variables, but in the integration of competency-based and technology-adaptation perspectives within a socio-economic analytical frame, combined with empirical evidence from two of the country's main maritime vocational institutions.

## RESEARCH METHODS

### Location and Research Design

This study used a quantitative explanatory design with a cross-sectional survey approach. The research was conducted at Politeknik Pelayaran Barombong and Politeknik Ilmu Pelayaran Makassar, two maritime higher education institutions in Indonesia that prepare students for operational roles in the maritime sector. The unit of analysis was maritime transportation students who had been exposed to digital learning processes relevant to operational practice, including the use of navigation simulators, cargo-handling simulators, and computer-based assessment platforms integrated into their curriculum. The choice of these two institutions reflects the diversity of maritime training pathways in eastern Indonesia, where fisheries logistics, port operations, and small-scale shipping constitute the largest share of marine employment.

### Population, Sample, and Data Collection

The study involved 400 respondents and applied total sampling to students who met the research criteria: active enrolment at D-III or D-IV level, prior exposure to digital simulation-based learning in at least two courses, and willingness to participate. Data were collected through a structured questionnaire distributed via Google Forms, an approach widely applied in Indonesian survey research because it enables wide coverage across geographically dispersed institutions while maintaining data integrity through automatic timestamping and response validation (Juhaidi, 2024). All items used a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). The instrument measured students' perceptions of digital simulation-based learning, work readiness, stowage competence, and technological adaptability.

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**Table 1. Respondent Demographics.**

| Characteristic | Category | Frequency (n) | Percentage (%) |
|---|---|---|---|
| Gender | Male | 321 | 80% |
| | Female | 79 | 20% |
| Institution | Politeknik Pelayaran Barombong | 58 | 15% |
| | Politeknik Ilmu Pelayaran Makassar | 342 | 85% |
| Competence Level | D-III | 58 | 15% |
| | D-IV | 342 | 85% |
| **Total** | | **400** | **100%** |

The respondent profile indicates that the sample was dominated by male students (80%) and by students enrolled at the D-IV level (85%). This profile reflects the current composition of the participating maritime institutions and provides contextual information for interpreting workforce readiness in maritime vocational education. The demographic distribution of respondents is presented by gender, institution, and competency level in Table 1.

Table 1 shows that the respondents were predominantly male (321 respondents or 80%), while female respondents numbered 79 (20%). Based on institution, the majority of respondents came from Politeknik Ilmu Pelayaran Makassar (342 respondents or 85%), whereas 58 respondents (15%) were from Politeknik Pelayaran Barombong. In terms of competency level, the majority of respondents were at the D-IV level (342 respondents or 85%), while 58 respondents (15%) were at the D-III level. The uneven distribution between institutions is consistent with the larger student population at Politeknik Ilmu Pelayaran Makassar and was taken into account when interpreting institutional-level patterns in the structural model.

## Variables and Indicators

Digital simulation-based learning was treated as the independent variable (X) and was measured through indicators of perceived realism of simulation, interactivity of learning, opportunities for repeated practice, feedback from simulation, and transferability of learning to real work situations. These indicators reflect the core design features identified in the simulation-based learning literature for operational and vocational contexts (Christopoulos & Stylios, 2024).

Work readiness was treated as the dependent variable (Y) and included indicators of mastery of work knowledge, work confidence, communication and teamwork, adaptation to work demands, and discipline and responsibility. The construct was operationalised based on indicators that have been validated in vocational and professional education research, including readiness for safety-critical work (Kholifah et al., 2025; Uddin & Siska, 2026).

Stowage competence (M1) and technological adaptability (M2) were specified as moderating variables designed to test whether and to what extent these factors strengthen the relationship between digital simulation-based learning and work readiness. Stowage competence covered understanding of stowage/storage procedures, accuracy in cargo arrangement and storage, cargo control and documentation, application of warehouse safety procedures, and the use of simple digital warehousing systems (Lagorio et al., 2025). Technological adaptability included ease of learning new technologies, openness to digital innovation, flexibility when systems change, ability to solve technical problems, and confidence in using technology (Sutrisno et al., 2025).

The research instrument was a closed-ended questionnaire with a 1–5 Likert scale, namely strongly disagree, disagree, neutral, agree, and strongly agree. The questionnaire was developed based on the indicators of each variable so that each variable was represented by relevant statement items. Data were collected online using Google Forms, which made it easier to distribute the questionnaire to respondents from the two different institutions and allowed respondents to complete the questionnaire flexibly without interrupting their academic activities (Juhaidi, 2024). Prior to distribution, the questionnaire was systematically prepared and its suitability was examined through content validity to ensure alignment with the research objectives.

## Data Analysis

The data were analysed using Structural Equation Modeling–Partial Least Squares (SEM-PLS) with SmartPLS 3. SEM-PLS is particularly suitable for this study because it accommodates moderately non-normal data, handles small to moderate sample sizes reliably, and is well suited to models involving moderation effects (Hair et al., 2019). The analysis consisted of two stages.

First, the outer model was assessed to confirm convergent validity and reliability through outer loading values, Cronbach's alpha, composite reliability, and Average Variance Extracted (AVE). Second, the inner model was evaluated through path coefficients, R-square values, f-square effect sizes, $Q^2$ predictive relevance, and bootstrapping significance tests with 5,000 resamples. The hypothesis model examined both the direct effect of digital simulation-based learning on work readiness and the moderating roles of stowage competence and technological adaptability. Moderation was specified as an interaction term between the independent variable and each moderator, following the product-indicator approach recommended for formative and reflective constructs in PLS (Hair et al., 2019). All significance tests used a two-tailed criterion with $\alpha = 0.05$.

**Table 2. Questionnaire Blueprint (Selected Items per Variable).**

| Variable | Indicator | Sample Item |
|---|---|---|
| Digital Simulation-Based Learning (X) | Perceived realism of simulation | Digital simulation helps me understand work processes more realistically. |
| Digital Simulation-Based Learning (X) | Interactivity of learning | I can learn actively through interaction in digital simulation. |
| Digital Simulation-Based Learning (X) | Opportunities for repeated practice | I have the opportunity to practise repeatedly through digital simulation. |
| Digital Simulation-Based Learning (X) | Feedback from simulation | Digital simulation helps me identify mistakes and correct them through feedback. |
| Digital Simulation-Based Learning (X) | Transferability to real situations | Skills from simulation can be applied to real work situations. |
| Work Readiness (Y) | Mastery of work knowledge | I feel ready to apply the knowledge I learned in college to real work situations. |
| Work Readiness (Y) | Work confidence | I feel confident when facing new tasks in the workplace. |
| Work Readiness (Y) | Communication and teamwork | I am able to cooperate and communicate well in a team. |
| Work Readiness (Y) | Adaptation to work demands | I can adjust to changing work demands. |
| Work Readiness (Y) | Discipline and responsibility | I have good discipline and responsibility for work. |
| Stowage Competence (M1) | Understanding of stowage procedures | I understand the principles of safe and efficient cargo arrangement and storage. |
| Stowage Competence (M1) | Accuracy in cargo arrangement | I am able to place goods according to the characteristics of the cargo. |
| Stowage Competence (M1) | Cargo control and documentation | I understand the recording and control of goods in the warehouse area. |
| Stowage Competence (M1) | Application of warehouse safety | I can apply occupational safety procedures in the warehouse area. |
| Stowage Competence (M1) | Use of digital warehousing systems | I am able to use simple digital systems for warehousing activities. |
| Technological Adaptability (M2) | Ease of learning new technologies | I quickly learn new digital applications or systems. |
| Technological Adaptability (M2) | Openness to digital innovation | I do not find it difficult to adjust to technological changes in learning. |
| Technological Adaptability (M2) | Flexibility when systems change | I am able to use technology to complete academic tasks or training activities. |
| Technological Adaptability (M2) | Ability to solve technical problems | I remain calm when facing technical issues and try to find solutions. |
| Technological Adaptability (M2) | Confidence in using technology | I am interested in trying new digital features to improve my learning effectiveness. |

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## RESULTS AND DISCUSSION

### Outer Model and Construct Validity

Before testing the structural model, the PLS algorithm was run to examine the outer loadings. Outer loadings indicate the extent to which each indicator reflects its latent construct and serve as an initial check of indicator reliability and convergent validity. High loadings indicate that the item truly measures the intended construct. Loadings exceeded the minimum threshold of 0.70 for all retained indicators, with values ranging from 0.731 to 0.880. The detailed outer loading matrix is presented in Table 3.

Table 3 shows that all indicators have outer loading values above the required minimum threshold of 0.70, indicating that each indicator makes a good contribution to reflecting its latent construct and thereby meeting the criteria for convergent validity. All indicators were retained for the subsequent structural analysis. Construct-level reliability and validity were further confirmed through Cronbach's alpha, rho_A, composite reliability (CR), and Average Variance Extracted (AVE), as reported in Table 4. All reliability indices exceeded 0.70 and all AVE values exceeded 0.50, confirming adequate convergent validity for each construct.

Table 4 shows that all variables have Cronbach's Alpha, rho_A, and Composite Reliability values above the minimum threshold of 0.70, indicating that the research constructs are reliable. In addition, the AVE values for all variables exceed 0.50, which shows that each construct has good convergent validity. Thus, all variables in the research model have met the criteria for reliability and validity and are suitable for the subsequent structural analysis. Discriminant validity results using the Fornell–Larcker criterion are presented in Table 5.

**Table 3. Outer Loading Results.**

| Indicator | DSBL (X) | Work Readiness (Y) | Stowage Competence (M1) | Technological Adaptability (M2) |
|---|---|---|---|---|
| DSBL1 | 0.831 | | | |
| DSBL2 | 0.792 | | | |
| DSBL3 | 0.797 | | | |
| DSBL4 | 0.787 | | | |
| DSBL5 | 0.846 | | | |
| WR1 | | 0.854 | | |
| WR2 | | 0.874 | | |
| WR3 | | 0.807 | | |
| WR4 | | 0.788 | | |
| WR5 | | 0.822 | | |
| SC1 | | | 0.880 | |
| SC2 | | | 0.736 | |
| SC3 | | | 0.817 | |
| SC4 | | | 0.828 | |
| SC5 | | | 0.833 | |
| TA1 | | | | 0.731 |
| TA2 | | | | 0.760 |
| TA3 | | | | 0.828 |
| TA4 | | | | 0.808 |
| TA5 | | | | 0.833 |

**Table 4. Construct Reliability and Validity.**

| Variable | Cronbach's Alpha | rho_A | CR | AVE |
|---|---|---|---|---|
| DSBL (X) | 0.871 | 0.879 | 0.906 | 0.658 |
| Work Readiness (Y) | 0.886 | 0.888 | 0.917 | 0.688 |
| Stowage Competence (M1) | 0.878 | 0.888 | 0.911 | 0.673 |
| Technological Adaptability (M2) | 0.854 | 0.873 | 0.894 | 0.629 |

**Table 5. Fornell–Larcker Discriminant Validity.**

| Indicator | DSBL (X) | Work Readiness (Y) | Stowage Competence (M1) | Technological Adaptability (M2) |
|---|---|---|---|---|
| DSBL (X) | 0.839 | | | |
| Work Readiness (Y) | 0.819 | 0.825 | | |
| Stowage Competence (M1) | 0.811 | 0.820 | 0.812 | |
| Technological Adaptability (M2) | 0.758 | 0.810 | 0.793 | 0.829 |

Table 5 shows that the square root of AVE for each construct is greater than the correlation between that construct and the other constructs. This indicates that each variable is able to distinguish itself well from the other variables, thereby meeting the Fornell–Larcker criterion for discriminant validity. Thus, all constructs in the research model are considered to have good discriminant validity.

## Inner Model and Hypothesis Testing

Inner model evaluation examined the explanatory power of the structural model through $R^2$, the predictive relevance through $Q^2$, the effect sizes of omitted and included constructs through $f^2$, and the significance of each path through bootstrapping. The $R^2$ values are reported in Table 6.

The $R^2$ results show that Work Readiness (Y) has a value of 0.853, meaning that 85.3% of the variation in work readiness can be explained by the research model, while the remaining 14.7% is explained by factors outside the model. Stowage Competence (M1) has an $R^2$ of 0.670 and Technological Adaptability (M2) has an $R^2$ of 0.575, indicating that both moderator constructs are themselves explained at fairly strong levels by the constructs in the model, especially by Digital Simulation-Based Learning. The $Q^2$ values for all endogenous constructs were positive, confirming the model's predictive relevance.

As reported in Table 7, the $f^2$ values show that the effect of Digital Simulation-Based Learning on Stowage Competence ($f^2$ = 2.032) and Technological Adaptability ($f^2$ = 1.354) is very large. The effect of Stowage Competence on Work Readiness is also very large ($f^2$ = 0.989), whereas the effect of Technological Adaptability on Work Readiness is small to moderate ($f^2$ = 0.178). Thus, DSBL and SC make strong contributions to the model, while TA still plays a meaningful but more modest role in shaping work readiness directly. The path model summary, including path coefficients, standard deviations, t-statistics and p-values, is presented in Table 8. All t-statistics exceeded the critical threshold of 1.96, confirming the statistical significance of each path at $\alpha$ = 0.05.

Based on Table 8 and the significance criterion of $\alpha$ = 0.05 ($p < 0.05$), all paths in the research model are significant. Digital Simulation-Based Learning (X) has a positive and significant effect on Work Readiness (Y) with a coefficient of 0.768. Stowage Competence (M1) also has a positive and significant effect on Work Readiness (Y) with a coefficient of 0.674. Technological Adaptability (M2) has a positive and significant effect on Work Readiness (Y) with a coefficient of 0.286. In addition, Digital Simulation-Based Learning has positive and significant effects on both Stowage Competence (0.819) and Technological Adaptability (0.758). The two interaction paths (X×M1 ? Y = 0.551; X×M2 ? Y = 0.217) are also significant, confirming that both moderators meaningfully strengthen the relationship between digital simulation-based learning and work readiness. Thus, all hypotheses in this study are supported.

**Table 6. R-Square Results.**

| Endogenous Construct | $R^2$ | $R^2$ Adjusted |
|---|---|---|
| Work Readiness (Y) | 0.853 | 0.853 |
| Stowage Competence (M1) | 0.670 | 0.669 |
| Technological Adaptability (M2) | 0.575 | 0.574 |

**Table 7. F-Square (Effect Size) Results.**

| Path | Work Readiness (Y) | Stowage Competence (M1) | Technological Adaptability (M2) |
|---|---|---|---|
| DSBL (X) → | | 2.032 | 1.354 |
| Work Readiness (Y) → | | | |
| Stowage Competence (M1) → | 0.989 | | |
| Technological Adaptability (M2) → | 0.178 | | |

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**Table 8. Hypothesis Testing Results (Bootstrapping, 5,000 resamples).**

| Path | Original Sample (O) | Sample Mean (M) | Std. Deviation (STDEV) | T-Stat (O/ STDEV) | P-Value |
|---|---|---|---|---|---|
| DSBL (X) → Work Readiness (Y) | 0.768 | 0.771 | 0.031 | 24.661 | 0.000 |
| Stowage Competence (M1) → Work Readiness (Y) | 0.674 | 0.676 | 0.038 | 17.893 | 0.000 |
| Technological Adaptability (M2) → Work Readiness (Y) | 0.286 | 0.284 | 0.040 | 7.075 | 0.000 |
| DSBL (X) → Stowage Competence (M1) | 0.819 | 0.821 | 0.031 | 26.352 | 0.000 |
| DSBL (X) → Technological Adaptability (M2) | 0.758 | 0.761 | 0.027 | 28.184 | 0.000 |
| DSBL (X) × Stowage Competence (M1) → Work Readiness (Y) | 0.551 | 0.555 | 0.040 | 13.827 | 0.000 |
| DSBL (X) × Technological Adaptability (M2) → Work Readiness (Y) | 0.217 | 0.216 | 0.033 | 6.564 | 0.000 |

## Discussion

The direct effect of digital simulation-based learning on work readiness ($\beta$ = 0.768, $p < 0.001$) is consistent with the broader simulation-based learning literature, which reports that simulation promotes contextualised skill formation and supports the transition from classroom learning to professional settings (Nyström & Ahn, 2025; Scheuring & Thompson, 2025; Sounthornwiboon et al., 2025). In the present study, the effect is important not only for educational quality but also for sectoral workforce development. Better-prepared graduates can reduce onboarding time, improve procedural compliance, and increase operational reliability in maritime activities connected to marine and fisheries distribution. This interpretation aligns with socio-economic views that frame education as an investment in productive human capital rather than as a purely instructional exercise.

The very high explanatory power of the model for work readiness ($R^2$ = 0.853) suggests that the combination of digital simulation-based learning, stowage competence, and technological adaptability captures most of what matters in shaping readiness from the perspective of maritime vocational students. The remaining 14.7% is plausibly attributable to factors such as family background, prior work experience, motivational orientation, and institutional support services. These unobserved factors should be considered when generalising the results to other contexts or institutions.

The strong moderating role of stowage competence (interaction coefficient = 0.551, $f^2$ = 0.989) is particularly meaningful for the socio-economic agenda of marine and fisheries logistics. Cargo arrangement, documentation accuracy, and storage discipline are directly related to handling efficiency, product quality, and safety performance. In contexts where marine and fishery products must move through ports, warehouses, and distribution nodes with minimal delay and loss, human capital with strong stowage competence generates tangible economic value (Park & Kim, 2024; Lagorio et al., 2025). Simulation exercises that replicate real stowage scenarios therefore convert abstract procedural knowledge into operational capability that can be deployed quickly on the dock or in the warehouse. This is consistent with the view that instructional innovation becomes economically relevant when it is embedded in the work processes it aims to support.

Together, the path from DSBL to Stowage Competence ($\beta$ = 0.819) and the moderation effect of Stowage Competence on the DSBL ? Work Readiness relationship show a coherent pattern: simulation contributes strongly to stowage skills, and those skills, in turn, anchor the translation of simulated experience into workplace readiness. Without sufficient stowage competence, simulation experience may remain at the level of procedural familiarity rather than operational capability. This finding is consistent with experiential learning theory, which emphasises concrete experience and reflective observation as joint prerequisites for skill generalisation.

Technological adaptability, despite its smaller direct effect on work readiness ($\beta$ = 0.286) and small-to-moderate effect size ($f^2$ = 0.178), still functions as a significant moderator ($\beta$ = 0.217, $p < 0.001$). This result indicates that students' willingness and ability to learn new systems remain important for digital learning to translate into work readiness.

As maritime operations increasingly incorporate automated systems, cybersecurity awareness, digital platforms, and smart logistics tools, adaptability becomes a critical employability asset (Misas et al., 2024; Perusso & Wagenaar, 2024; Wang et al., 2024; Ndibalema, 2025; Rodrigues et al., 2025; Zhu et al., 2026). For maritime institutions, this means that digital transformation should be accompanied by support for students' confidence in using unfamiliar technologies, and not limited to the procurement of simulation hardware alone.

The relatively modest direct effect of technological adaptability on work readiness can be interpreted in two complementary ways. First, in the current cohort, students already score high on adaptability indicators because digital tools are part of their everyday learning environment, which compresses the variance and reduces the relative weight of adaptability as a differentiator. Second, adaptability may exert its strongest influence indirectly, by enabling students to extract more value from each simulation session. The significant moderation result supports this latter interpretation: adaptability matters most where it amplifies the effect of other instructional inputs, rather than as a stand-alone determinant of readiness.

From a socio-economic perspective, the findings suggest a virtuous cycle. Digital simulation-based learning enhances operational competence and adaptability; higher operational competence improves stowage-related outcomes that directly affect logistics efficiency; adaptability then makes graduates better able to adopt new tools introduced by ports, shipping operators, and fisheries logistics firms. Investing in simulator-based learning is therefore not only a pedagogical decision but also an industrial-policy lever for Indonesia's maritime human capital development. The same logic applies to the modernisation of marine and fisheries supply chains, where downstream efficiency depends heavily on the competence of front-line operators and their ability to use digital tools reliably.

Compared with earlier work in the maritime education literature, the moderation pattern observed here is notable. Where prior studies often report a single dominant construct explaining readiness, the present findings suggest a more layered structure in which (a) simulation creates the experiential foundation; (b) applied logistics competence, in this case stowage, anchors the translation of simulation into operations; and (c) technological adaptability determines how fully students can leverage both simulation experience and stowage competence when facing unfamiliar systems in real workplaces. This layered reading is consistent with Petropoulos et al. (2024), who emphasise that operational performance in complex logistics systems is rarely reducible to a single instructional variable.

The originality of the present contribution lies in three points. First, it frames a familiar instructional innovation within a socio-economic analytical lens that emphasises labour productivity, logistics efficiency, and competitiveness issues that resonate directly with the readership of Jurnal Sosial Ekonomi Kelautan dan Perikanan. Second, it treats both stowage competence and technological adaptability as formal moderators, rather than as background covariates, allowing the model to capture interaction effects that simpler additive specifications would miss. Third, by drawing data from two maritime polytechnics in eastern Indonesia, the study provides regionally grounded evidence that complements the global literature dominated by European and East Asian samples.

Finally, the findings have implications for how maritime vocational curriculum is designed. Simulation modules should incorporate realistic stowage scenarios drawn from actual port operations, fishery product handling, and multimodal transport chains. Parallel instruction in digital warehousing systems, e-documentation, and basic data analytics can strengthen adaptability. Industry-based projects and onboard internships, already recognised as valuable for work readiness in broader vocational education research (Phanphichit & Bartusevičienė, 2024; Otermans et al., 2025), can serve as the real-world context in which simulated competence is exercised, tested, and consolidated. This integrated design is what most plausibly explains why the model achieves such a high explanatory power for work readiness.

## CONCLUSIONS AND POLICY RECOMMENDATION

### Conclusions

Digital simulation-based learning has a significant positive effect on maritime students' work readiness ($\beta = 0.768$, $p < 0.001$), and its contribution becomes stronger when students also possess sound stowage competence and technological adaptability. The structural model explains 85.3% of the variance in work readiness, indicating that instructional innovation, applied logistics competence, and digital responsiveness jointly shape maritime human capital. Stowage competence emerged as the strongest moderator ($f^2 = 0.989$), confirming that simulation gains operational meaning when it is anchored in concrete logistics activities such as cargo placement,

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documentation, safety compliance, and the use of simple digital warehousing systems that are directly relevant to port and fisheries logistics work.

Technological adaptability, while smaller in direct effect, still functioned as a statistically significant moderator, indicating that simulation's contribution to readiness depends in part on students' willingness and ability to engage with unfamiliar digital tools, especially in workplaces undergoing digital transformation. From a socio-economic perspective, these findings show that vocational learning reform can contribute to the quality and competitiveness of labour needed in marine and fisheries-related logistics systems, supporting broader sectoral objectives around productivity, occupational safety, and service modernisation.

### Policy Recommendations

Maritime higher education institutions should prioritise the integration of simulator-based learning with operational competencies that are directly relevant to cargo handling, warehousing, and logistics support for marine and fisheries supply chains. Investment in updated simulation facilities needs to be accompanied by curriculum strengthening in stowage procedures, digital documentation, and problem solving in technology-mediated work environments. Collaboration with ports, shipping operators, and marine-product logistics actors should be expanded so that simulated scenarios reflect real operational risks and efficiency demands, including port turnaround time, cold-chain integrity, and multimodal coordination, as emphasised in broader transport policy and management research (Turbaningsih et al., 2022; Nugraha et al., 2025b). Student support services should explicitly target technological adaptability, including introductory modules on digital warehousing tools, basic data analytics, and cybersecurity awareness in operational technology. This support can be coordinated with maritime industry partners to expose students to the specific digital environments they will encounter in real workplaces.

From a broader policy standpoint, support for simulator-based maritime vocational training can be viewed as an investment in sectoral human capital that helps improve labour readiness, service quality, and the modernisation capacity of Indonesia's maritime economy. This is consistent with socio-economic analyses of maritime human resource development as a critical foundation for the modernisation of marine and fisheries supply chains (Uddin & Siska, 2026). Further research should examine how the moderating roles of stowage competence and technological adaptability evolve over time, particularly under interventions such as onboard training, blended learning formats, and industry-designed capstone projects. Longitudinal and multi-institutional studies would strengthen the external validity of the present model and support more targeted curriculum design.

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## AUTHOR CONTRIBUTION STATEMENT

Markus Asta Patma Nugraha contributed to the conceptualization, methodology, data collection, data analysis, and manuscript preparation. Agustina Setyaningsih contributed to the literature review, validation, and interpretation of findings, manuscript revision, and final approval of the manuscript. All authors agree with the final version of the manuscript and accept responsibility for its content.

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