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Research Article

Integrating STEM and work-based learning to enhance competency and job readiness in maritime higher education

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The rapid transformation of the global workplace triggered by the Industrial Revolution 4.0 has increased the demand for graduates who possess not only technical competencies, but also adaptive problem-solving and professional skills. This challenge is increasingly important in maritime higher education, where learning environments are complex and high-risk. However, current learning approaches still struggle to effectively integrate conceptual learning with authentic workplace experiences, resulting in a gap between education and industry needs. This study aims to develop and validate an integrative STEM–Work-Based Learning model to improve students' competency, job readiness, and professional character in maritime higher education. This study employed a Design-Based Research approach combined with a quasi-experimental design and Structural Equation Modeling analysis. The research involved 120 students selected through purposive sampling from maritime higher education institutions in Indonesia. Data were analyzed using independent sample *t*-tests, N-Gain analysis, Confirmatory Factor Analysis, and Structural Equation Modeling. The findings indicate that the developed model effectively improved students' competency, job readiness, and professional character through the integration of interdisciplinary STEM learning and authentic workplace experiences. This study contributes a validated pedagogical framework integrating STEM and Work-Based Learning for maritime higher education. The findings provide practical implications for designing contextual and industry-oriented vocational learning to better prepare graduates for the demands of the modern workforce.

Keywords: Employability; Maritime education; Professional competence; STEM-WBL integration; Vocational pedagogy; Work readiness

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1. Introduction

The rapid transformation of the global workplace driven by the Industrial Revolution 4.0 and digital transformation has fundamentally changed the competency profile required of higher education graduates (Sudarsono et al., 2024; Tee et al., 2024; Wong et al., 2025). Modern industries increasingly demand not only technical expertise but also higher-order thinking skills, adaptability, problem-solving abilities, collaboration, and professional attitudes relevant to dynamic work environments (Rios et al., 2020). Consequently, vocational and professional education institutions are required to redesign learning systems that are more contextual,

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interdisciplinary, and aligned with workforce demands.

In the maritime sector, these challenges are becoming increasingly complex because maritime workplaces operate in high-risk and safety-critical environments requiring technical precision, rapid decision-making, discipline, and strong professional responsibility (Dewan et al., 2023; Kim et al., 2021). However, learning practices in maritime higher education are still largely dominated by procedural and instructor-centered approaches emphasizing compliance with operational standards rather than developing adaptive and integrative competencies (Sudarsono et al., 2024, 2025). Although these approaches are important for maintaining safety standards, they often fail to optimally develop students' critical thinking, collaborative problem-solving, and work readiness skills required in rapidly changing industrial contexts (Quintanilla et al., 2023).

To address these challenges, STEM (Science, Technology, Engineering, and Mathematics) education has been widely recognized as an effective approach for promoting interdisciplinary learning, creativity, and higher-order thinking skills. STEM-based learning enables students to connect scientific concepts with real-world applications and supports the development of analytical and problem-solving abilities essential for future employment (Le & Nguyen, 2023; Yaki, 2022). Previous studies also indicate that STEM learning contributes positively to innovation, creativity, and technological competence in vocational education contexts (Ivan et al., 2025; Mauricio et al., 2024).

On the other hand, Work-Based Learning [WBL] has been identified as an effective pedagogical approach for improving students' employability and work readiness through authentic workplace experiences (Olofsson, 2026; Sudarsono, 2020). Through internships, industrial projects, and experiential learning activities, students are able to internalize professional values, workplace culture, and practical competencies directly relevant to industrial needs (Aliaga et al., 2026; Kristiawan et al., 2025). WBL also strengthens the relationship between academic learning and professional practice, enabling students to develop competencies that are more transferable to workplace settings.

Recent studies have increasingly emphasized workplace-relevant and competency-oriented learning in vocational, engineering, and professional higher education contexts. Graduate preparation is therefore not limited to the acquisition of technical competencies; rather, it involves the development of practical readiness, professional communication, career adaptability, critical thinking, problem-solving, teamwork, and the capacity to respond to changing work environments (Dülger & Övdür Uğurlu, 2025; Kholifah et al., 2024; Moldashev et al., 2026; Thi Hong & Hang Thi, 2026). Research has shown that graduates who participate in authentic learning experiences and industry-engaged educational activities demonstrate higher levels of work readiness, career adaptability, and professional confidence compared to those educated through conventional classroom-based approaches (Adegbite & Hoole, 2024; Aduli et al., 2022; Reverte et al., 2025). Consequently, higher education institutions are increasingly encouraged to redesign curricula that foster both disciplinary expertise and transferable employability skills.

Within vocational education, the integration of learning experiences across academic and workplace settings has emerged as a promising strategy for addressing the persistent mismatch between educational outcomes and labor market expectations. Studies on Work-Based Learning have demonstrated that internships, industry placements, apprenticeships, and project-based collaborations can facilitate the development of professional identity, workplace communication, teamwork, and problem-solving skills (Kristiawan et al., 2025; Syed et al., 2025). Similarly, STEM education has been widely recognized for promoting analytical reasoning, innovation, and interdisciplinary thinking through authentic problem-solving activities (Fikri et al., 2026; Gürsoy et al., 2023; Le & Nguyen, 2023; Portillo-Blanco et al., 2025; Thi Hong & Hang Thi, 2026; Uzun & Şen, 2023). However, much of the existing literature has examined STEM and Work-Based Learning as separate educational interventions, resulting in limited understanding of how both approaches may complement one another within a unified pedagogical framework.

The need for such integration is particularly relevant in maritime higher education. Maritime industries are undergoing significant transformation due to digitalization, automation, smart shipping technologies, and evolving international safety regulations. These developments require future maritime professionals to possess not only strong technical competencies but also adaptive decision-making abilities, collaborative problem-solving skills, and professional responsibility in complex operational environments (Dewan et al., 2023; Kim et al., 2021). Nevertheless, previous studies indicate that maritime education often remains focused on procedural compliance and technical training, with insufficient emphasis on interdisciplinary learning and the holistic development of employability competencies. Therefore, there is a growing need for pedagogical models capable of integrating conceptual STEM knowledge, workplace experiences, and professional character development to prepare graduates for the demands of contemporary maritime industries.

Despite the recognized benefits of STEM and Work-Based Learning, existing studies generally examine these approaches separately. Although STEM and WBL have individually demonstrated positive impacts on vocational learning, few studies have developed and empirically validated an integrated STEM–WBL framework specifically for maritime higher education. In addition, limited research has investigated how professional character dimensions such as discipline, integrity, responsibility, and safety awareness contribute to students' work readiness within integrated vocational learning environments. This indicates important theoretical and empirical gaps in vocational education research, particularly in safety-critical educational contexts such as maritime higher education (Naseer et al., 2025; Portillo-Blanco et al., 2025).

The importance of this study lies in its attempt to address these gaps by integrating STEM and Work-Based Learning within a unified pedagogical framework specifically designed for maritime higher education. Unlike conventional vocational learning approaches, the proposed model combines conceptual STEM learning, authentic workplace experiences, industrial projects, and professional character development into a structured learning system. This integration is expected to produce graduates who are not only technically competent but also professionally prepared to face the demands of high-risk industrial environments.

Based on these gaps, this study develops and validates an integrative STEM–Work-Based Learning model designed specifically for maritime higher education. The proposed model integrates conceptual learning, authentic workplace experiences, and professional character development into a unified pedagogical framework. Unlike previous studies, this research combines Design-Based Research [DBR], quasi-experimental methods, and Structural Equation Modeling [SEM] analysis to provide both conceptual and empirical validation of the proposed model.

Specifically, this study aims to develop and validate an integrative STEM–Work-Based Learning model for maritime higher education, examine its effect on students' competency and work readiness, and investigate the role of professional character in strengthening students' work readiness. Accordingly, the study is guided by three research questions:

RQ 1) Does the integrative STEM–Work-Based Learning model improve student competency?

RQ 2) Does the model enhance students' work readiness?

RQ 3) What is the role of professional character in influencing work readiness within the integrative learning framework?

1.1. STEM Education in Vocational and Maritime Contexts

Recent developments in vocational education have highlighted the growing importance of STEM education as a mechanism for preparing students to address complex industrial and technological challenges. STEM learning promotes interdisciplinary integration and encourages learners to apply scientific knowledge, engineering design, technological tools, and mathematical reasoning to solve authentic problems. Previous studies have shown that STEM-oriented instructional models can significantly improve students' creativity, innovation, technical competence, critical thinking, and employability-related skills in vocational settings (Arsad & Heong, 2024; Fathoni et al., 2020;

Laksono & Kuncahyono, 2026). Furthermore, STEM-based project learning enables students to connect classroom learning with industrial applications while fostering problem-solving and collaborative skills that are increasingly required in modern workplaces. Such findings suggest that STEM education serves not only as a pedagogical innovation but also as a strategic framework for workforce preparation in technology-intensive sectors (Abdullah & Triwahyuni, 2025; Marfuah & Khikmawati, 2023).

In maritime education, STEM integration is increasingly important because maritime industries are undergoing rapid transformation driven by automation, digital technologies, sustainability initiatives, and smart operational systems. Future maritime professionals must therefore possess interdisciplinary competencies that combine technical expertise with analytical thinking, technological literacy, and adaptive problem-solving. As educational institutions increasingly adopt digital and technology-enhanced pedagogies, students are expected to develop the capacity to operate within complex and rapidly evolving professional environments (Çakır & Güner, 2026; Tusyanah et al., 2026). Despite these demands, many maritime training programs continue to emphasize procedural and technical instruction rather than integrated problem-solving experiences. This situation indicates the need for pedagogical frameworks that combine STEM principles with contextual workplace learning to support the development of comprehensive professional competencies required in contemporary maritime environments.

1.2. Work-Based Learning and Employability Development

Work-Based Learning [WBL] has been widely recognized as one of the most effective approaches for connecting educational experiences with workplace expectations. Through authentic engagement in professional environments, students are able to develop technical expertise while simultaneously strengthening communication, teamwork, problem-solving, and professional decision-making skills (Abrahamson et al., 2025; Thi Hong & Hang Thi, 2026). Research in vocational education has demonstrated that authentic workplace experiences contribute significantly to graduate employability because students learn to transfer academic knowledge into practical applications and professional performance (Dahlback et al., 2020). Moreover, authentic workplace-based assessment has been shown to improve learners' ability to demonstrate integrated competence rather than fragmented theoretical knowledge, thereby supporting a smoother transition from education to employment.

The effectiveness of WBL is closely associated with authentic learning environments that provide opportunities for reflection, coaching, and self-directed learning. Previous studies have argued that meaningful vocational learning occurs when students actively participate in realistic professional situations rather than passively receive information through traditional instruction (Schaap et al., 2011). Authentic and self-directed learning experiences encourage students to develop vocational identities, professional judgment, and adaptive competencies that are essential for career success. Furthermore, pedagogical approaches that emphasize learner engagement, collaboration, and practical application have been associated with stronger employability outcomes and greater workplace readiness (La et al., 2026; Liu & Tian, 2024). Consequently, vocational education institutions are increasingly encouraged to redesign curricula that systematically integrate workplace experiences into academic learning processes to strengthen employability outcomes.

1.3. Professional Character and Work Readiness

In addition to technical competence, contemporary employability literature emphasizes the importance of professional character as a critical determinant of work readiness. Professional character encompasses discipline, responsibility, integrity, resilience, interpersonal skills, and commitment to professional standards. These attributes influence how individuals apply their knowledge and skills within workplace settings and determine their ability to adapt to changing professional demands. Research indicates that work readiness is shaped not only by technical qualifications but also by psychological, behavioral, and interpersonal factors that support successful workplace adjustment and long-term career development (Liu & Tian, 2024; Tusyanah et al., 2026).

Within vocational education, professional character development is increasingly viewed as an integral component of workforce preparation. Studies have shown that employability and work readiness are strengthened when educational programs deliberately cultivate self-management, resilience, communication skills, and professional responsibility alongside technical competencies. Innovative pedagogical approaches that encourage reflective learning, collaboration, and learner autonomy have been found to support the development of these professional attributes (La et al., 2026; Orhani & Alija, 2026). In high-risk sectors such as maritime industries, these characteristics become particularly important because operational effectiveness depends not only on technical proficiency but also on ethical behavior, safety awareness, teamwork, and accountability. Therefore, professional character should be positioned as a central component within integrated vocational learning frameworks aimed at preparing graduates for complex workplace environments.

2. Method

2.1. Research Design

This study employed a Design-Based Research approach integrated with a quasi-experimental design and Structural Equation Modeling analysis to develop and validate an integrative STEM–Work-Based Learning model for maritime higher education. DBR was selected because it enables iterative development, implementation, evaluation, and refinement of educational interventions in authentic learning environments (Design-Based Research Collective, 2003; Reeves, 2006). The study was conducted over one academic semester (16 weeks) through two iterative cycles consisting of needs analysis, model design, implementation, evaluation, and revision.

The intervention consisted of 12 learning sessions (150 minutes each) combining classroom learning, laboratory practice, industry-based projects, and workplace learning activities. The experimental group received the integrative STEM–Work-Based Learning model, while the control group received conventional instruction.

2.2. Research Subjects and Locations

The study involved 120 students from three maritime higher education institutions in Indonesia selected using purposive sampling. Participants were second- and third-year marine engineering students aged 19–23 years who had participated in laboratory and industrial practice activities. The sample consisted of 72 male and 48 female students, divided into an experimental group ($n = 60$) and a control group ($n = 60$).

The sample size was considered adequate for covariance-based SEM because SEM generally requires a minimum sample size of 5–10 times the estimated parameters (Buchberger et al., 2024).

2.3. Research Procedures

The study began with a needs analysis through classroom observations, interviews, and curriculum analysis. The initial STEM–Work-Based Learning model was then designed and implemented for 12 weeks with two meetings per week.

STEM integration was conducted through interdisciplinary industry-based projects such as engine maintenance diagnostics, ship electrical troubleshooting, and safety-based operational simulations. Before implementation, lecturers participated in a two-day workshop on STEM integration, Work-Based Learning strategies, authentic assessment, and safety procedures.

2.4. Instruments and Data Collection

The study used several instruments to measure cognitive and non-cognitive outcomes. The Competency Test consisted of 30 multiple-choice and problem-solving items. The Work Readiness Questionnaire consisted of 24 items, while the Professional Character Scale included 20 items, both measured using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree).

All instruments were developed by the researchers based on previous literature related to vocational education, STEM learning, employability, and professional character. The instruments were validated by five experts in vocational education, maritime training, STEM pedagogy, and educational measurement. Construct validity was examined using Confirmatory Factor Analysis [CFA], while reliability was tested using Cronbach's Alpha and Composite Reliability. The validity and reliability results showed that all instruments met acceptable standards. CFA results indicated factor loadings ranging from 0.62 to 0.88, AVE values from .53 to .71, and Composite Reliability [CR] values from .81 to .93. Cronbach's Alpha coefficients ranged from .78 to .91, indicating good reliability. In addition, discriminant validity was confirmed because the square root of AVE exceeded the inter-construct correlations. These findings indicate that the instruments were valid and reliable for measuring competency, job readiness, and professional character.

2.5. Data Analysis

The data were analyzed using SPSS version 26 and AMOS version 24. SPSS was used for descriptive statistics, normality tests, *t*-tests, N-Gain analysis, and effect size calculations, while AMOS was used for covariance-based SEM (CB-SEM) analysis. The significance level was set at $p < .05$. Normality assumptions were examined using the Kolmogorov–Smirnov test. Effect size interpretation followed Cohen's criteria: 0.20 = small, 0.50 = medium, and 0.80 = large. SEM analysis included measurement model evaluation through CFA and structural model testing using goodness-of-fit indices such as CFI, TLI, RMSEA, and Chi-square/df.

Normality assumptions were evaluated using skewness and kurtosis values. The results showed that all variables had skewness values ranging from −1.12 to 0.94 and kurtosis values ranging from −1.25 to 1.41, indicating normal data distribution because all values were within the acceptable range of ±2.00. Therefore, the data met the assumptions required for parametric and SEM analyses.

3. Results

3.1. Model Validation

The integrating STEM and Work-Based Learning was developed through two cycles of Design-Based Research and validated by five experts consisting of vocational education specialists, STEM pedagogy experts, and maritime industry practitioners. The expert validation rubric evaluated four aspects: (1) content relevance, (2) instructional design, (3) industry relevance, and (4) practicality of implementation using a 5-point scale ranging from 1 = very poor to 5 = excellent.

The validation results showed an average score of 4.52/5.00, categorized as very valid. Inter-rater agreement among validators reached 0.87, indicating high consistency among expert evaluations. The validity criteria used in this study were: 4.21–5.00 = very valid; 3.41–4.20 = valid; 2.61–3.40 = moderately valid; 1.81–2.60 = less valid; and 1.00–1.80 = invalid.

To illustrate the initial design developed during the first Design-Based Research cycle, Figure 1 presents the preliminary integrative STEM–Work-Based Learning model. The model shows how STEM learning activities, workplace practice, and professional competency development were initially conceptualized in maritime higher education. At this stage, STEM learning and workplace practice were still treated as relatively separate instructional components. Although students engaged in both conceptual STEM learning and workplace-oriented activities, the connections among classroom instruction, industrial projects, and professional competency development remained limited. In addition, professional character development and performance-based assessment had not yet been fully embedded in the learning system. Therefore, the initial design served as an exploratory framework for identifying weaknesses and determining areas for refinement in the subsequent development cycle.

Following expert evaluation and reflection from the first implementation cycle, the model was revised to strengthen the integration between STEM learning, industrial projects, workplace practice, and professional character development. Figure 2 presents the refined integrative STEM–Work-Based Learning model developed in Cycle 2.

Figure 1
STEM–Work-Based Learning Integrative Model (Cycle 1: Initial Design)

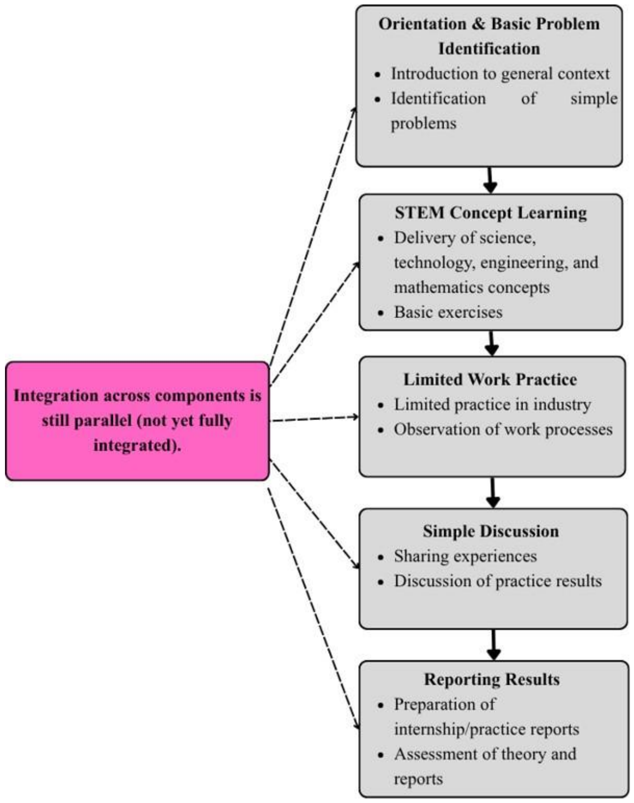

Figure 2
STEM–Work-Based Learning Integrative Model (Cycle 2: Final Integrated Model)

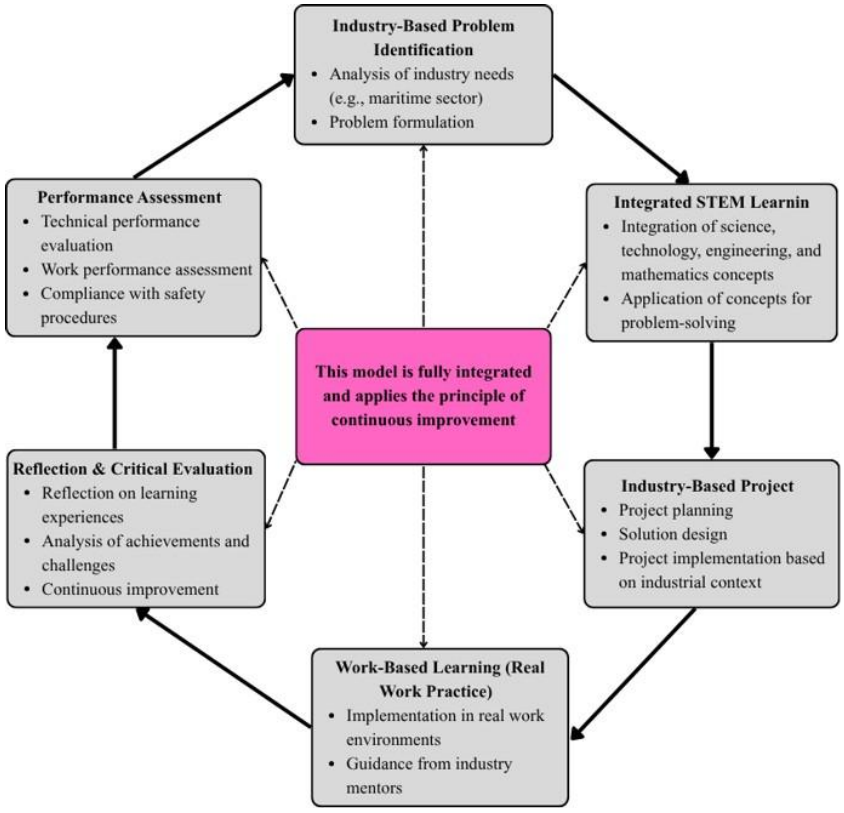

Figure 2 illustrates the final integrated model developed after the revision process in Cycle 2. Compared with the initial model, the revised framework demonstrates stronger alignment between interdisciplinary STEM learning, authentic workplace experiences, industrial projects, and performance-based assessment. The model also integrates professional character dimensions, such as discipline, responsibility, integrity, and safety awareness, as central learning outcomes. This refinement resulted in a more contextual, industry-oriented, and comprehensive vocational learning framework capable of supporting competency and employability development in maritime higher education.

Table 1 presents the detailed characteristics of the initial STEM–Work-Based Learning model developed during Cycle 1. The table summarizes the structure, instructional focus, assessment mechanisms, and identified weaknesses of the preliminary model.

Table 1
STEM–Work-Based Learning Integrative Model (Cycle 1: Initial Design)

Phase/Component	*Detailed Description*
Main Focus	Initial integration between STEM concepts and Work-Based Learning (WBL) activities to introduce the link between theory and practice in the context of marine education.
Activity Structure	Learning consists of two main components: (1) STEM learning in the classroom/laboratory and (2) work experience through industrial practice. Both activities are still running in parallel and have not been systematically integrated.
Learning Stages	1) Orientation & identification of basic problems 2) Learning STEM concepts 3) Limited work practice 4) Simple discussions 5) Reporting of results
The Role of Lecturers	Conceptual learning facilitator and practice guide, but has not yet integrated the two activities thoroughly.
Role of Students	Following theoretical and practical learning separately, with involvement in problem solving still limited.
Professional Character	Focus on mastering technical skills (hard skills) and basic understanding of marine science, without a strong emphasis on occupational safety aspects.
Industrial Project Linkages	Industrial projects are supplementary in nature and are not yet a core part of the learning process.
Assessment Mechanism	Assessment is focused on mastery of theory and practical/internship reports, and does not yet use integrated performance assessment.
Contextual Relevance	Academically valid, but still general in nature and does not fully reflect the complex needs of the marine industry.
Main Weaknesses	Low integration between theory and practice, assessment is not yet comprehensive, and professional character has not developed optimally.

As shown in Table 1, the initial model primarily emphasized the introduction of STEM concepts alongside workplace practice; however, both components were still implemented independently rather than through a fully integrated pedagogical structure. The learning stages focused mainly on conceptual understanding and limited practical exposure, while industrial projects functioned only as supplementary activities. In addition, assessment procedures were still dominated by theoretical evaluation and internship reporting, without integrated performance assessment aligned with workplace standards. These findings indicate that the Cycle 1 model required substantial refinement to strengthen contextual learning, interdisciplinary integration, and professional character development.

Table 2 summarizes the characteristics of the final integrative STEM–Work-Based Learning model developed after the refinement process in Cycle 2.

Table 2
STEM–Work-Based Learning Integrative Model (Cycle 2: Final Integrated Model)

Phase / Component	*Detailed Description*
Main Focus	Full integration between STEM, Work-Based Learning, and learning outcomes (CP) that are measurable and relevant to the needs of the marine industry.
Activity Structure	Learning activities are designed in an integrated and sequential manner, connecting conceptual learning, industrial projects, work practices, and assessments into one complete system.
Learning Stages	1) Industry-based problem identification 2) Integrated STEM learning 3) Industry-based projects 4) Work-Based Learning (real work practice) 5) Critical reflection & discussion 6) Performance assessment
The Role of Lecturers	Learning designer, theory-practice integration facilitator, and industry-standards-based student performance evaluator.
Role of Students	Actively engage in real-world problem solving, work on industry projects, and critically reflect on learning experiences.
Professional Character	Developed comprehensively to include discipline, responsibility, integrity, and safety-critical awareness as core components.
Industrial Project Linkages	Industrial projects become learning centers (core learning) that are directly connected to competency targets and the needs of the world of work.
Assessment Mechanism	Using integrated performance assessments, including technical competence, work effectiveness, quality of results, and compliance with safety procedures.
Contextual Relevance	Very high, in accordance with the needs of the high-risk marine industry and demands comprehensive work readiness.
Model Advantages	Strong integration between theory and practice, comprehensive assessment, and simultaneous development of competencies and character.

Table 2 shows that the final model achieved a substantially higher level of integration between conceptual learning, workplace practice, industrial projects, and competency assessment. Unlike the initial model, industrial projects became the core component of learning activities and were directly linked to competency targets and workplace demands. The model also incorporated integrated performance assessment, enabling evaluation of both technical competency and professional behavior. Furthermore, professional character development was positioned as an essential component of the learning process, particularly regarding safety-critical awareness and professional responsibility relevant to maritime industry contexts.

The difference between the Cycle 1 and Cycle 2 models lies in the level of readiness, structure, and effectiveness of their implementation. Cycle 1 is an initial design stage that is still exploratory with learning syntax that is not yet fully structured, integration of components (such as STEM and Work-Based Learning) that is still limited, the role of teachers is relatively dominant, and student involvement is not optimal so that the results obtained tend to be less than optimal and function more as a basis for reflection. Cycle 2 is a refinement stage developed based on the evaluation of Cycle 1 with a more systematic and operational syntax, stronger component integration, the role of teachers as facilitators, increased student activity and collaboration, implementation of learning that is more contextual to the world of work, the use of more comprehensive evaluation instruments, and produces more effective and optimal learning outcomes.

3.2. Instrument Validity and Reliability Test

The measurement model was evaluated using Confirmatory Factor Analysis. The measurement model demonstrated acceptable goodness-of-fit indices with CFI = 0.93, TLI = 0.92, RMSEA =

0.049, and Chi-square/df = 1.95, indicating good model fit. The CFA results showed that all indicators had factor loadings ranging from 0.62 to 0.88, meeting the acceptable threshold (>0.50). The Average Variance Extracted [AVE] values ranged from 0.53 to 0.71, while Composite Reliability values ranged from .81 to .93, indicating adequate convergent validity and internal consistency reliability. Cronbach's Alpha coefficients ranged from 0.78 to 0.91.

Discriminant validity was confirmed because the square root of AVE for each construct exceeded the inter-construct correlations. In addition, all Variance Inflation Factor [VIF] values were below 5.00, indicating no multicollinearity issues among indicators.

3.3. Effectiveness of Learning Models

The results of the initial equivalence test showed no significant difference between the experimental and control groups in the pretest scores ($p > .05$), indicating comparable initial abilities. After the implementation of the integrative STEM–Work-Based Learning model, the experimental group demonstrated significantly higher improvement compared to the control group.

Descriptively, the experimental group's competency score increased from M = 68.4 (SD = 6.21) to M = 84.7 (SD = 5.48), while the control group increased from M = 67.9 (SD = 6.08) to M = 75.3 (SD = 5.96).

To examine the effectiveness of the proposed learning model, pretest and posttest comparisons were conducted between the experimental and control groups. Table 3 presents the comparison results, including effect size analysis.

Table 3

Pretest–Posttest Comparison and Effect Size

Group	*Pretest(SD)*	*Posttest (SD)*	*t*	*df*	*p*	*Δ Score*	*Cohen's d*	*95% CI*	*Interpretation*
Experiment	68.4(6.21)	84.7 (5.48)	9.84	59	<.001*	+16.3	0.92	[0.68–1.16]	Large
Control	67.9(6.08)	75.3 (5.96)	4.12	59	<.001*	+7.4	0.41	[0.18–0.63]	Moderate

Note. *: $p < .05$ indicates statistically significant improvement between pretest and posttest scores.

As presented in Table 3, both groups experienced improvement after the learning intervention; however, the experimental group demonstrated substantially greater gains compared to the control group. The experimental group achieved a mean score increase of 16.3 points with a large practical effect size (Cohen's d = 0.92), whereas the control group showed only moderate improvement. These findings indicate that the integrative STEM–Work-Based Learning model was significantly more effective in improving students' competencies than conventional instructional approaches. The large effect size further suggests that the model produced meaningful educational impact within maritime higher education contexts.

3.4. Structural Equation Modeling Analysis

3.4.1. Model goodness of fit test

The SEM analysis results indicate that the model has a good level of fit with the data. The CFI value = 0.94, TLI = 0.93, and RMSEA = 0.048, which meet the model feasibility criteria. The Chi-square/df value = 1.87 indicates the model is in the fit category. All indicators meet the requirements of the measurement model. Thus, the structural model can be used for hypothesis testing.

SEM analysis was conducted to empirically examine and confirm the significance of the hypothesized relationships in the proposed framework. The significant beta coefficients obtained from the SEM results indicate that the conceptual model presented in Figure 2 is empirically supported and demonstrates good structural validity in the context of maritime higher education.The final SEM model confirms the hypothesized relationships among the variables in the proposed framework. The integrative STEM–Work-Based Learning model demonstrated significant direct effects on competency ($\beta = 0.72$, $p < .001$), work readiness ($\beta = 0.65$, $p < .001$), and professional character (β = 0.61, $p < .001$). In addition, competency significantly influenced work readiness (β = 0.58, $p < .001$), while professional character also had a significant contribution to work readiness (β = 0.49, $p < .001$). These findings confirm that the proposed model is empirically supported and demonstrates strong relationships between cognitive, affective, and employability-related dimensions within maritime higher education

3.4.2. Hypothesis testing

To evaluate the structural relationships among the variables within the proposed framework, hypothesis testing was conducted using Structural Equation Modeling. Table 4 presents the results of the hypothesis testing.

Table 4
Hypothesis Test Results

Hypothesis	*Connection*	*β Coefficient*	*p-value*	*Information*
H1	Model → Competence	0.72	<.001	Significant
H2	Model → Work Readiness	0.65	<.001	Significant
H3	Model → Professional Character	0.61	<.001	Significant
H4	Competence → Work Readiness	0.58	<.001	Significant
H5	Character → Work Readiness	0.49	<.001	Significant

Table 4 indicates that all hypothesized relationships within the structural model were statistically significant. The strongest direct effect was observed between the integrative STEM–Work-Based Learning model and student competency (β = 0.72), followed by work readiness and professional character development. In addition, both competency and professional character significantly contributed to work readiness, confirming that employability outcomes are shaped through the interaction of cognitive and affective dimensions. These results provide empirical support for the proposed conceptual framework and demonstrate the effectiveness of integrating STEM learning with authentic workplace experiences in maritime higher education.

4. Discussion

The results of this study indicate that the integrative STEM–Work-Based Learning model has a significant impact on improving students' competency, job readiness, and professional character. These findings reinforce the view that technical and cognitive competencies remain the primary foundations of employability, particularly in complex and dynamic workplace contexts (Adegbite & Hoole, 2024; Reverte et al., 2025; Thapa, 2024). The findings further suggest that integrating interdisciplinary STEM learning with authentic workplace experiences creates a more meaningful and contextual learning environment capable of strengthening both cognitive and professional competencies simultaneously.

Theoretically, these results align with the STEM approach, which emphasizes the integration of cross-disciplinary knowledge to develop higher-order thinking skills. Recent research shows that STEM-based learning, particularly when combined with project-based approaches, can significantly enhance creativity, problem-solving abilities, and 21st-century skills (Asrizal et al., 2026; Ivan et al., 2025; Mauricio et al., 2024; Oanh & Dang, 2025). However, this study extends previous research by demonstrating that STEM learning becomes more effective when systematically integrated with Work-Based Learning within authentic maritime industry contexts. Through this integration, students are not only able to understand conceptual knowledge but also apply it directly to workplace-related situations requiring decision-making, collaboration, and adaptive problem-solving skills (Funa, 2026; Portillo-Blanco et al., 2025; Rantschl et al., 2025).

These findings also extend previous studies that positioned Work-Based Learning as a complementary component of academic instruction. In this study, Work-Based Learning functioned as a core pedagogical component that connected classroom learning, industrial projects, and workplace practice into an integrated learning system, significantly improving students' job readiness (Aliaga et al., 2026; Kristiawan et al., 2025; Syed et al., 2025). This finding supports previous studies indicating that Work-Based Learning is an effective transdisciplinary approach for bridging the gap between education and professional practice (Fergusson, 2024; Kärkkäinen et al., 2025). In addition, direct workplace experiences such as internships and industry-based projects have been consistently shown to strengthen employability and workplace preparedness (Aduli et al., 2022; Alharethi et al., 2025).

The effectiveness of the proposed model can also be interpreted through the perspective of experiential learning theory, which emphasizes that meaningful learning occurs through authentic experience, reflection, and contextual problem solving. In the present study, students actively engaged in solving real-world maritime industry problems through integrated STEM and workplace-oriented activities. This process appears to strengthen not only conceptual understanding but also the ability to transfer knowledge into professional practice. In the context of rapid digital transformation and automation, this integration becomes increasingly important because vocational graduates are expected to possess both technical expertise and adaptive workplace competencies (Filipe & Baptista, 2024; Mhaske et al., 2025).

One important contribution of this study is the strengthening of the role of professional character in shaping job readiness. The findings indicate that job readiness is influenced not only by technical competency but also by non-cognitive dimensions such as discipline, responsibility, integrity, and safety awareness. This result is particularly relevant within maritime education, where professional practice occurs in high-risk and safety-critical environments requiring strict compliance with operational procedures and ethical responsibility. Recent studies similarly emphasize that employability development depends not only on academic competency but also on soft skills and professional attitudes formed through contextual and workplace-oriented learning experiences (Fernando et al., 2025; Suyatmo et al., 2025).

Furthermore, this study provides a deeper understanding of the structural relationships among competency, professional character, and job readiness (Laode et al., 2020). The findings indicate that competency acts as the primary cognitive pathway mediating the relationship between learning models and job readiness, while professional character serves as the affective pathway strengthening this relationship (Veronika et al., 2025; Yao & Lin, 2025). This finding contributes to employability theory by demonstrating that job readiness is shaped through the interaction of cognitive, technical, and affective dimensions rather than through technical competency alone. The results therefore reinforce the importance of integrated vocational pedagogy that simultaneously develops hard skills and professional values through authentic learning experiences.

While the results of this study are generally consistent with international literature, several important differences should be highlighted. Compared with previous STEM-based vocational learning studies that generally reported moderate competency improvements, this study demonstrated a relatively stronger practical effect. One possible explanation is the stronger contextual integration between STEM learning, industrial projects, and workplace practice implemented within maritime education. In addition, the contribution of professional character appears particularly important within maritime contexts because maritime professions place strong emphasis on safety awareness, discipline, responsibility, and teamwork in high-risk working environments (Yushan et al., 2021; Sukesi et al., 2023). These contextual characteristics may strengthen the effectiveness of integrated STEM–Work-Based Learning beyond what has been reported in more general vocational education settings.

5. Limitations

This study has several limitations that should be considered when interpreting the findings. First, the research was conducted only in three maritime higher education institutions in Indonesia, which may limit the generalizability of the results to other vocational or international educational contexts. Second, the duration of the intervention was relatively limited, so the long-term impact of the integrative STEM–Work-Based Learning model on students' professional development could not be fully examined. Third, several instruments used in this study relied on self-reported responses, which may introduce subjective bias in measuring work readiness and professional character. In addition, although the study employed a quasi-experimental design and Structural Equation Modeling analysis, the absence of random assignment may still allow the influence of uncontrolled external variables. Therefore, future research is recommended to involve larger and more diverse samples, apply longitudinal designs, and integrate multiple sources of data such as industry supervisor evaluations and workplace performance assessments to strengthen the validity and generalizability of the findings.

6. Conclusions

This study developed and validated an integrative STEM–Work-Based Learning model for maritime higher education using a Design-Based Research approach combined with quasi-experimental and Structural Equation Modeling analyses. The findings demonstrate that the proposed model effectively enhances students' competency, job readiness, and professional character through the integration of interdisciplinary STEM learning, authentic workplace experiences, and industry-based projects.

The novelty of this study lies in the integration of STEM and Work-Based Learning within a unified pedagogical framework specifically designed for maritime higher education, a context that has received limited empirical attention in previous studies. The findings also highlight the important role of professional character, particularly discipline, responsibility, and safety awareness, in strengthening students' readiness for professional practice within safety-critical environments.

From a theoretical perspective, this study contributes to experiential learning theory, vocational pedagogy, and employability research by demonstrating that job readiness is shaped through the interaction of cognitive, technical, and affective dimensions developed through authentic learning experiences. Practically, the proposed model offers a relevant framework for designing contextual and industry-oriented vocational learning capable of addressing the evolving demands of the global workforce.

Overall, the integration of STEM and Work-Based Learning provides a comprehensive and sustainable approach for improving the quality and relevance of maritime higher education in the era of industrial transformation.

7. Implications

Theoretically, this study contributes to experiential learning theory, vocational pedagogy, and employability theory by showing that competency and job readiness are not developed through isolated instructional activities, but through the integration of cognitive, technical, and affective dimensions within authentic learning environments. By combining STEM learning with Work-Based Learning, the study extends previous research by positioning these two approaches within a unified pedagogical framework rather than treating them as separate instructional strategies. The findings also highlight professional character as an important theoretical component of job readiness, especially in safety-critical vocational contexts such as maritime education.

Practically, the findings suggest that vocational educators should design learning activities that connect STEM concepts, industry-based projects, and authentic workplace experiences within a structured learning system. Such integration can help students relate theoretical knowledge to real occupational tasks and develop competencies that are relevant to professional practice. The use of performance-based assessment aligned with workplace standards is also important, as it enables educators to evaluate not only students' conceptual understanding but also their technical skills and professional preparedness. In this regard, stronger collaboration between educational institutions and industry partners is essential to ensure that learning experiences remain responsive to current workforce demands.

From a policy perspective, this study emphasizes the need for vocational education policies that support industry-oriented, integrative, and competency-based learning approaches. Educational institutions and policymakers should promote curriculum flexibility, strengthen institutional partnerships with industry, and incorporate professional character and occupational safety competencies as core learning outcomes. Such policy support is necessary to prepare graduates who are not only technically competent but also adaptable, responsible, and ready to meet the demands of rapidly changing professional environments.

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Conflict of Interest: The authors declare that there are no conflicts of interest regarding the publication of this paper. The research was conducted independently without any financial or commercial influence that could bias the results.

Data Availability: The data utilized and examined in this research can be obtained from the corresponding author upon reasonable request. Access to the datasets will be provided in accordance with applicable research and ethical considerations.

Ethics Declaration: Ethical clearance for this study was granted by the Institutional Review Board of Yogyakarta Maritime College, Indonesia (Approval No. YMC/IRB/2024/017). All research procedures involving human participants complied with the ethical guidelines established by the institution and adhered to the principles outlined in the Declaration of Helsinki. Prior to participation, informed consent was obtained from all respondents. Participants were fully informed about the purpose of the study, data confidentiality measures, and their freedom to discontinue participation at any point without penalty or adverse consequences.

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