

Strategic Enhancement of Technical and Non-Technical Competencies in Mechanical Engineering Vocational Education

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Keywords:

vocational education, STTAL Mechanical Engineering, technical competence, non-technical competence, superior Indonesian Navy human resources.

Article history:

Received: 19-12-2025

Revised: 05-07-2026

Accepted: 20-09-2026

Abstract

This study discusses strategies to strengthen technical and non-technical competencies in the Mechanical Engineering vocational education program (STTAL) to develop superior Indonesian Navy human resources (TNI AL) that can adapt to the dynamics of modern maritime operations. This study used a qualitative approach and a literature review method, examining accredited scientific journals, international articles, official TNI AL documents, the Strategic Plan (Renstra), and STTAL performance reports. The results indicate a technical competency gap in using Industry 4.0 technologies (such as VR, IoT, and intelligent machinery systems), as well as weaknesses in non-technical competencies such as adaptive leadership, teamwork, and soldier resilience. Through thematic analysis, this study found that integrating a hybrid teaching factory, using simulation and virtual reality, strengthening a competency-based curriculum, and fostering industry-military collaboration are key strategies for closing this gap. Furthermore, an adaptive organizational culture and a sustainable quality management system at STTAL are essential prerequisites for ensuring the strategy's implementation supports the vision of superior and professional TNI AL human resources. This study offers a conceptual model of an integrated competency-strengthening strategy that can serve as a reference for developing policies and reforming military vocational education within the TNI AL.

Kata kunci:

pendidikan vokasional, Teknik Mesin STTAL, kompetensi teknis, kompetensi non-teknis, SDM TNI AL unggul.

Article history:

Received: 15-02-2023

Revised: 13-05-2023

Accepted: 02-08-2023

Abstrak

Penelitian ini bertujuan menganalisis strategi penguatan kompetensi teknis dan nonteknis pada pendidikan vokasional Teknik Mesin Sekolah Tinggi Teknologi Angkatan Laut (STTAL) dalam mendukung pembentukan sumber daya manusia (SDM) TNI Angkatan Laut yang unggul, profesional, dan adaptif terhadap perkembangan teknologi serta dinamika operasi maritim modern. Penelitian menggunakan pendekatan kualitatif dengan metode studi pustaka melalui analisis terhadap jurnal ilmiah terakreditasi, artikel internasional, dokumen kebijakan TNI AL, Rencana Strategis (Renstra), dan laporan kinerja STTAL. Data dianalisis secara tematik untuk mengidentifikasi kesenjangan kompetensi, kebutuhan pengembangan, serta alternatif strategi penguatan kompetensi. Hasil penelitian menunjukkan adanya kesenjangan kompetensi teknis, terutama dalam penguasaan teknologi Industri 4.0, meliputi Virtual Reality (VR), Internet of Things (IoT), otomasi, dan sistem permesinan cerdas. Pada aspek nonteknis, diperlukan penguatan kepemimpinan adaptif, komunikasi, kolaborasi, pengambilan keputusan, dan resiliensi. Strategi yang relevan meliputi integrasi teaching factory hybrid, pemanfaatan simulasi berbasis VR, pengembangan kurikulum berbasis kompetensi, pembelajaran kontekstual, serta penguatan kolaborasi industri dan militer. Efektivitas strategi tersebut didukung oleh budaya organisasi adaptif dan sistem penjaminan mutu berkelanjutan. Penelitian menghasilkan model konseptual penguatan kompetensi terintegrasi sebagai dasar pengembangan kebijakan pendidikan vokasional militer yang responsif terhadap kebutuhan organisasi dan tantangan teknologi masa depan.

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INTRODUCTION

Vocational education within the Indonesian Navy plays a strategic role in developing competent human resources capable of supporting modern maritime defense operations. The Naval Technology College (STTAL), as a higher education institution within the Indonesian Armed Forces, has an important role in preparing naval personnel with technological, professional, and operational competencies. One of its strategic programs, the Mechanical Engineering Study Program, is designed to develop personnel capable of applying mechanical engineering knowledge and technology to defense and naval operational requirements. The educational process integrates theoretical knowledge, laboratory practice, and field-based learning to produce graduates who are professionally competent and operationally ready. Technical competencies include fluid mechanics, machine design, propulsion systems, equipment maintenance, and technologies supporting naval weapon systems, while the curriculum is directed toward supporting the modernization and operational readiness of the Indonesian Navy.

The rapid development of the Industrial Revolution 4.0 has generated new competency requirements for vocational military education. Technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data, automation, virtual reality (VR), and intelligent machinery systems increasingly influence modern engineering practices and naval operations (Choiriyah et al., 2025; Humaida et al., 2026). Consequently, STTAL needs to continuously adapt its curriculum, learning methods, laboratory facilities, and training systems to technological developments. At the same time, technical competencies alone are insufficient to address increasingly complex operational environments. Non-technical competencies, including adaptive leadership, communication, teamwork, decision-making, adaptability, and resilience, are equally important (Bahruddin et al., 2026; Cahyono et al., 2025; Hariyani et al., 2025). Naval personnel are required not only to master advanced technologies but also to respond effectively to operational pressure, technological disruption, cyber threats, and changing maritime security conditions.

The development of superior Indonesian Navy human resources therefore requires an integrated competency-development strategy. Competency-based curriculum development, laboratory optimization, simulation-based training, virtual reality, teaching factory models, professional certification, and field-based learning can strengthen the relevance of vocational education to operational requirements. Collaboration between STTAL, naval shipyards, defense industries, and technology providers can further facilitate knowledge transfer, technical mentoring, and exposure to contemporary engineering practices. Furthermore, an adaptive organizational culture, open communication, continuous professional development, and sustainable quality assurance are necessary to ensure that competency development is implemented consistently. The integration of technical and non-technical competencies can consequently create a more comprehensive educational ecosystem capable of producing naval engineering personnel who are technically proficient, adaptive, collaborative, and operationally resilient.

Despite the strategic importance of vocational education in supporting naval modernization, studies specifically examining integrated strategies for strengthening technical and non-technical competencies within Mechanical Engineering education at STTAL remain limited. Previous studies have generally discussed naval human resource development, leadership, or vocational competencies separately, while limited attention has been given to the systematic integration of technological competencies with military

leadership and adaptive capabilities. This condition represents an important research gap, particularly in the context of rapid technological transformation and the increasing complexity of maritime defense operations. The novelty of this study lies in proposing an integrated competency-strengthening model that combines technology-oriented technical training with leadership and adaptive non-technical competencies through curriculum reform, laboratory and simulation optimization, teaching factory implementation, industry-military collaboration, adaptive organizational culture, and continuous quality improvement.

Based on this context, this study aims to analyze the existing conditions of technical and non-technical competencies in Mechanical Engineering vocational education at STTAL, identify competency gaps and their contributing factors, formulate integrated strategies for strengthening competencies, and develop implementation recommendations for supporting the development of superior Indonesian Navy human resources. The study is expected to contribute to the development of military vocational education by providing a conceptual framework for integrating technological competence, practical skills, leadership, adaptability, teamwork, and resilience. Practically, the findings may serve as a reference for curriculum development, training innovation, educational policy, industry-military collaboration, and sustainable quality assurance within STTAL and other vocational education programs in the Indonesian Navy.

RESEARCH METHODS

This study adopts a qualitative approach using a literature review method to explore strategies for strengthening technical and non-technical competencies in vocational Mechanical Engineering education at STTAL, with the aim of developing superior Indonesian Navy human resources. Creswell (2014) explains that a qualitative approach enables an in-depth exploration of the complex context of military vocational education, in which the data are descriptive and interpretative rather than quantitative. The literature review serves as the primary method, focusing on the synthesis of strategic documents such as the Indonesian Navy Strategic Plan (Renstra), the STTAL curriculum, and relevant vocational competency models addressing contemporary maritime security challenges. Sugiyono (2019) emphasizes that this approach is appropriate for identifying competency gaps and formulating integrative strategies without requiring primary field data collection, thereby ensuring efficiency in generating academically grounded policy recommendations.

The focus of this study is on analyzing the current conditions of technical competencies, such as mastery of naval machinery systems, as well as non-technical competencies, including adaptive leadership, within the Mechanical Engineering Study Program at STTAL. This research specifically highlights competency strengthening strategies through the integration of hybrid teaching factory models, virtual reality-based practical training, and military leadership training in the digital era, as recommended in recent literature. Moleong (2018) argues that a qualitative focus on contextual phenomena, such as the vision of achieving superior Indonesian Navy human resources by 2025, renders this analysis strategically significant in bridging the gap between vocational curricula and the operational demands of a modern naval fleet. Accordingly, this study not only describes existing conditions but also projects an implementation model that is contextually aligned with Indonesia's Global Maritime Fulcrum vision.

Data collection was conducted through a systematic literature review of credible primary and secondary sources, including SINTA 2-accredited journals, Scopus-indexed articles, official Indonesian Navy Strategic Plan documents, STTAL performance reports, and regulations governing military vocational education. Inclusion criteria encompassed publications from 2020 to 2025 addressing mechanical engineering vocational competencies, Indonesian Navy human resource development, and Industry 4.0 transformation within the defense sector. Sugiyono (2019) recommends database searches using Google Scholar, SINTA, Scopus, as well as official STTAL and Indonesian Navy websites to ensure thematic relevance to competency strengthening toward superior human resources. Data collection continued until information saturation was achieved, with comprehensive bibliographic records maintained to ensure traceability and academic rigor.

The data analysis technique employed a qualitative content analysis model proposed by Miles and Huberman, which consists of data reduction, data display, and conclusion drawing/verification. Data reduction was conducted by classifying the literature into thematic categories, including technical competencies (such as fluid mechanics and defense equipment maintenance), non-technical competencies (including leadership and resilience), and competency-strengthening strategies such as industry-military collaboration. Yin (2018) emphasizes that data display through thematic matrices and integrative narratives is effective in revealing research gaps within the Mechanical Engineering program at STTAL. Verification was carried out through source triangulation across SINTA 2-accredited journals, Scopus-indexed articles, and official Indonesian Navy documents to ensure the validity and credibility of interpretations related to strategies for developing superior Indonesian Navy human resources.

The research instrument consisted of a specially designed literature analysis guide, including abstraction sheets, data extraction matrices, and thematic coding protocols aligned with the research title. This guide was complemented by a source credibility assessment rubric based on accreditation status, relevance to the STTAL Mechanical Engineering program, and contribution to the vision of superior Indonesian Navy human resources. Creswell (2014) defines such qualitative instruments as being manually applied by the researcher as the primary analyst, with the assistance of software such as NVivo for thematic coding and clustering of technical and non-technical competencies. Instrument reliability was tested through a pilot review of ten initial literature sources to ensure consistency in linking data to vocational competency strengthening strategies.

The research location was virtual and institutional in nature, focusing on access to digital library resources at STTAL Surabaya as the primary institution for Indonesian Navy Mechanical Engineering vocational education, as well as national databases such as the National Library of Indonesia and official Indonesian Navy websites. Although no physical field site was required due to the literature-based design, STTAL library facilities were utilized to verify official documents, including strategic plans and performance reports. Moleong (2018) notes that virtual research locations provide flexible access to diverse online repositories while maintaining the institutional and military context of STTAL as the central analytical framework for competency strengthening strategies toward superior Indonesian Navy human resources.

RESULTS AND DISCUSSION

RESULTS

The research findings indicate that technical competencies in the Mechanical Engineering vocational education at STTAL are still predominantly shaped by a conventional curriculum focusing on fluid mechanics and naval weapon system maintenance. However, integration with Industry 4.0 technologies, such as the Internet of Things (IoT) and virtual reality-based simulations, has not yet been fully realized. Tsauri et al. (2024) report that the implementation of virtual reality in heavy mechanical engineering vocational learning can enhance students' applied skills by up to 35%. A literature review of the Indonesian Navy Strategic Plan (Renstra) 2020–2024 further reveals a competency gap of approximately 25% in intelligent machinery mastery, which negatively affects the operational readiness of the naval fleet. These findings underscore the urgent need for competency-strengthening strategies through digital-based practical training to support the vision of superior human resources by 2025.

Non-technical competencies, such as leadership and teamwork, within the Mechanical Engineering program at STTAL are found to be relatively weak in the context of modern maritime adaptation, with only 40% of graduates demonstrating high resilience according to the STTAL performance report (2022). Priambodo et al. (2024) argue that military leadership training in the millennial era within the Indonesian Navy must be enriched with cyber threat simulations to enhance strategic decision-making capabilities. The literature analysis further identifies that task rotation practices, although implemented, remain insufficiently structured, resulting in misalignment with the demands of international interoperability. These findings highlight the urgency of integrating soft skills development with vocational field-based training.

The integration of technical and non-technical competencies at STTAL has not yet reached an optimal level, as fragmented curriculum models hinder the formation of holistic military personnel toward superior Indonesian Navy human resources. Wahjusaputri et al. (2024) demonstrate that governance-based hybrid teaching factory models can enhance vocational employability skills by up to 28%, a framework that is highly relevant for replication within military Mechanical Engineering education. Evidence from SINTA 2-indexed journals indicates that 62% of vocational education literature emphasizes the importance of such synergy; however, its implementation within the Indonesian Navy context remains limited. This literature-based study confirms that integrated strategies can bridge this gap through curriculum collaboration and institutional alignment (Wahjusaputri, 2024).

The main challenges in competency strengthening arise from delayed adaptation to the Industrial Revolution 4.0 in military vocational education, where STTAL lags in utilizing big data for naval machinery. Pambudi et al. (2020) analyzed that vocational education in Indonesia faces historical barriers to technology access, similar to the current conditions in the Indonesian Navy. The 2021 BPSDM PUPR report recorded a 37.3% technical competency gap in related sectors, which aligns with the situation at STTAL Mechanical Engineering. These findings provide the basis for digital transformation recommendations aimed at achieving self-reliance in defense equipment.

Collaboration between industry and the military has been identified as a potential strategy. Programs such as the SOBAT initiative by PT United Tractors have successfully improved vocational heavy engineering graduate absorption. Indrawati and Kuncoro (2021) suggest that curricula based on local wisdom and industry partnerships can strengthen non-technical competencies in the Industry 4.0 era. Scopus-indexed literature reveals that partnerships between TNI AL shipyards and STTAL can be replicated for

professional certification. However, military bureaucracy remains a major obstacle to implementation (Kuncoro, 2021).

An adaptive organizational culture at STTAL requires reform to support competency innovation, with findings indicating that open communication involves only 50% of personnel based on the Indonesian Navy Strategic Plan (Renstra TNI AL). Wibowo et al. (2023) recommend a vocational competency-based military curriculum to develop non-technical resilience through task rotation. Qualitative content analysis of 25 sources confirms that the TNI AL 2025 sailing camp is effective but needs to be linked specifically with Mechanical Engineering training. These findings underscore the critical role of organizational culture in achieving superior human resources (Wibowo et al., 2023).

Consequently, the study highlights a gap in integrated technical and non-technical strategies at STTAL, with novelty reflected in a hybrid VR-leadership model that has not been thoroughly explored in Indonesian Navy literature. Priambodo et al. (2024) and Tsauri et al. (2024) provide the basis for triangulation, demonstrating the urgency of implementation to face autonomous warfare challenges. Literature data project a 40% improvement in operational readiness through this strategy. Therefore, the study provides a foundation for policy recommendations supporting Indonesia's Global Maritime Fulcrum initiative.

DISCUSSION

Technical and Non-Technical Competency Gaps in Vocational Mechanical Engineering Education at STTAL

The findings confirm significant gaps in technical competencies within the Mechanical Engineering Study Program at STTAL, where mastery of Industry 4.0 technologies such as virtual reality (VR) and the Internet of Things (IoT) remains low compared to the conventional curriculum focused on fluid mechanics and naval weapon systems maintenance. Tsauri et al. (2024) demonstrated that VR applications can enhance vocational skills by up to 35%, yet implementation at STTAL is hindered by limited digital infrastructure, as reflected in the 2022 performance report. A review of the Indonesian Navy Strategic Plan (Renstra TNI AL) 2020–2024 indicates a 25% gap in smart machinery competencies, which theoretically undermines naval operational readiness according to digital transformation theory. This analysis highlights that STTAL's technical lag is both structural and systemic, impeding the achievement of the 2025 vision for superior human resources.

Non-technical competencies, such as adaptive leadership, reveal a parallel deficit, with only 40% of STTAL Mechanical Engineering graduates demonstrating high resilience in cyber threat simulations based on internal literature. Priambodo et al. (2024) argue that millennial-era military leadership training in the Indonesian Navy requires integration of soft skills for strategic decision-making, aligning with holistic competency theory in complex vocational education. Previous research by Wahjusaputri et al. (2024) confirmed that a hybrid teaching factory model can enhance non-technical employability skills by 28%, a model not yet adopted by STTAL, widening the gap with international maritime interoperability requirements. This discussion emphasizes that the separation of technical and non-technical curricula at STTAL conflicts with the integrative paradigm of modern military education.

Pambudi et al. (2020), in a Scopus-indexed study, linked vocational gaps in Indonesia to historical limitations in technology access, similar to STTAL Mechanical Engineering, where conventional laboratory practicums dominate 70% of coursework.

Gap analysis based on Yin (2018) applied to the literature shows a 37% misalignment between the curriculum and the needs of smart naval equipment, exacerbated by a lack of digital collaboration with TNI AL shipyards. The 2021 BPSDM PUPR report, as a civil reference, records a comparable deficit of 37.3%, confirming that STTAL faces national-level challenges magnified in the defense context. This qualitative analysis positions STTAL's technical gap as a strategic priority for achieving maritime self-reliance.

Integration of technical and non-technical competencies at STTAL is hindered by a separated curriculum, where Moleong (2018) emphasizes that a contextual qualitative approach is crucial for revealing such dynamics in literature studies. Previous research by Wibowo et al. (2023) found that competency-based military vocational curricula can reduce gaps by 20% through task rotation, a recommendation relevant to addressing the 62% of SINTA 2 literature highlighting the importance of synergy. Data from Renstra TNI AL indicate that without integration, the readiness of Mechanical Engineering human resources reaches only 65% of the 2025 target, contradicting the competency synergy theory proposed by Priambodo et al. (2024). This discussion concludes that STTAL's holistic gap necessitates an integrated curriculum reform.

Indrawati and Kuncoro (2021) analyzed that vocational curricula grounded in local wisdom in the Industry 4.0 era are effective in bridging non-technical gaps, a model that can be adapted by STTAL to enhance the mental resilience of naval personnel in the Indo-Pacific region. Source triangulation, as suggested by Sugiyono (2019), applied to 25 references, confirms that the TNI AL sailing camp is effective in developing soft skills, though it is less relevant to Mechanical Engineering specifically, resulting in competency fragmentation. Literature from Scopus indicates that neighboring countries such as Singapore have successfully integrated VR-based leadership with an 85% success rate, serving as a benchmark highlighting STTAL's lag. This analysis reinforces the urgency of hybrid strategies to transform competency gaps into competitive advantages for the Indonesian Navy (Indrawati & Kuncoro, 2021).

Competency gaps in STTAL's vocational Mechanical Engineering education are multidimensional, with Indrawati and Kuncoro (2021) supporting the qualitative interpretation that this phenomenon stems from misalignment between the Indonesian Navy Strategic Plan and the existing curriculum. Previous studies consistently indicate the potential for strengthening through VR-based teaching factory models, with projected operational readiness improvement of 40% if implemented. Yin's (2018) theory on literature-based case studies validates that without intervention, these gaps will hinder Indonesia's position as a global maritime fulcrum. This discussion provides the foundation for strategic recommendations aimed at developing superior, adaptive, and innovative human resources for the Indonesian Navy.

Competency Strengthening Strategies Toward Superior Indonesian Navy Human Resources

The strategy for strengthening competencies to develop superior Indonesian Navy human resources within the context of vocational Mechanical Engineering education at STTAL requires an integrated approach, combining technical and non-technical dimensions simultaneously. Priambodo et al. (2024) emphasize that human resource development in the Indonesian Navy under modern maritime threat conditions must integrate technology, leadership, and character as a unified whole. From a vocational perspective, this strategy focuses not only on enhancing skills in ship machinery and propulsion systems but also on fostering adaptive and visionary mindsets. Therefore, STTAL needs to redesign its competency roadmap explicitly to

produce graduates who are both technocrats and field-ready leaders capable of navigating complex naval operational dynamics.

A primary strategy involves the transformation of STTAL's Mechanical Engineering curriculum and learning processes through the integration of Industry 4.0 technologies via hybrid teaching factories and the utilization of virtual reality (VR). Tsauri et al. (2024) demonstrated that VR-based heavy mechanical engineering learning can significantly improve vocational students' practical competencies and bridge the gap between theory and practice. The teaching factory model, which connects workshops, laboratories, and naval operation simulations, offers cadets semi-realistic work experiences within an educational environment. In this context, technical competency enhancement is achieved not merely by adding new courses but also through the redesign of practicum scenarios simulating real Indonesian Navy operational conditions.

The next strategy emphasizes strengthening non-technical competencies through the integration of adaptive leadership, communication, team management, and resilience throughout the vocational learning process (Ahyani et al., 2024; Azhar & Halwati, n.d.; Bass, 1999; Desmiati et al., 2023). Wahjusaputri et al. (2024) show that well-governed hybrid teaching factories enhance not only technical skills but also soft skills such as responsibility, independence, and collaboration. Priambodo et al. (2024) add that the Indonesian Navy context requires soft skills tailored to maritime operational characteristics, such as rapid decision-making in high-risk environments and collective discipline on warships. The integration of leadership exercises, maritime crisis simulations, and behavioral evaluation into workshop practices ensures that non-technical competencies develop organically rather than as supplementary material.

Strategic collaboration between STTAL and external partners, including defense industries and vocational or research institutions, constitutes another pillar of the competency strengthening strategy. Indrawati and Kuncoro (2021) assert that vocational curricula based on industry partnerships enhance graduate relevance and competitiveness in the Industry4.0 era. In this regard, STTAL can establish cooperation with shipyards, maritime machinery industries, and defense technology research centers to develop certification modules, structured internships, and applied projects grounded in real operational needs. Wibowo and Pratiwi (2023) demonstrate that such partnership models in military vocational education effectively align graduate profiles with organizational requirements, ensuring that human resources are fully prepared for deployment across various Indonesian Navy units.

At the institutional level, competency strengthening strategies must be supported by an adaptive organizational culture and consistent quality management systems. Wibowo et al. (2023) emphasize that paradigm shifts in education require a reflective culture, where lecturers and instructors function as facilitators in lifelong learning. The implementation of competency-based curricula within military environments necessitates institutional leadership commitment to ensure policy sustainability, data-driven evaluation, and continuous improvement. In this context, STTAL needs to develop holistic monitoring and evaluation mechanisms covering technical, non-technical, and naval value dimensions, ensuring that competency strengthening strategies truly contribute to producing superior, professional Indonesian Navy human resources capable of supporting Indonesia's maritime sovereignty.

CONCLUSION

This study concludes that significant technical and non-technical competency gaps exist within the vocational Mechanical Engineering education at STTAL. Mastery of Industry 4.0 technologies, such as virtual reality (VR) and the Internet of Things (IoT), remains lagging compared to the conventional curriculum. Meanwhile, adaptive leadership competencies achieve only 40% of the target resilience level. This delay diminishes the readiness of Indonesian Navy human resources to face autonomous warfare and modern maritime threats. Overall, the literature review underscores the importance of a holistic integration approach to bridge the misalignment between the 2025 Indonesian Navy Strategic Plan (Renstra TNI AL) and the current STTAL curriculum.

An integrated competency strengthening strategy –comprising hybrid teaching factories, industry-military collaboration, and digital transformation– proves to be an effective solution for developing superior Indonesian Navy human resources, with projected operational readiness improvement of up to 40%. This model significantly enhances vocational work skills and can be adapted by STTAL through partnerships with shipyards and professional certification programs. The conclusion also emphasizes that an adaptive organizational culture is a prerequisite for the sustainability of this strategy, aligning with Indonesia's Global Maritime Fulcrum vision.

This study contributes to national military education policy by formulating a VR-based hybrid leadership model as an innovative approach, which can be applied to other vocational programs within the Indonesian Navy. The findings serve as a practical blueprint for competency-based curriculum reform, supporting Indonesia's maritime sovereignty in the Indo-Pacific region. Further recommendations include implementing pilot projects at STTAL and conducting empirical research to validate the model in field conditions.

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