

Exploring Digital Competency Needs for Robotics Integration in Malaysian TVET Education: A Narrative Review

Marlila Idris, Azda Azlin Ros, Che Ghani Che Kob^{*}

Faculty of Technical and Vocational, Sultan Idris Education University

Email: m20241000330@siswa.upsi.edu.my, m20241000331@siswa.upsi.edu.my

Corresponding Author Email: cheghani@ftv.upsi.edu.my

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Abstract

This narrative review explores the digital competency needs required for effective robotics integration in Malaysian Technical and Vocational Education and Training (TVET). The review synthesizes existing evidence on the digital competencies expected of TVET educators, examines the challenges associated with robotics implementation in teaching and learning, and identifies future directions for research and professional development. The increasing adoption of robotics technologies driven by Industry 4.0 and Education 4.0 has heightened expectations for TVET institutions to produce graduates equipped with relevant digital and technical competencies. However, robotics integration in Malaysian TVET remains constrained by varying levels of educators' digital competence, limited pedagogical readiness, insufficient professional development opportunities, and disparities in institutional infrastructure and policy support. A narrative review approach was employed by examining peer-reviewed journal articles, conference proceedings, government reports, policy documents, and international competency frameworks published primarily between 2019 and 2025. The selected literature was analyzed thematically to identify recurring concepts, emerging trends, research gaps, and practical implications. The review identified six key themes underpinning effective robotics integration, namely digital literacy, pedagogical competence, technical proficiency, curriculum alignment, institutional readiness, and continuous professional learning. The findings indicate that successful robotics integration requires educators to possess not only technical knowledge of robotics systems but also the pedagogical competencies needed to design technology-enhanced learning environments. The review further highlights inconsistencies in digital competency standards across institutions, limited empirical evidence on robotics competencies among Malaysian TVET educators, and inadequate alignment between existing competency frameworks and robotics-related teaching practices. Overall, this review provides an integrated understanding of the digital competency requirements necessary for sustainable robotics integration in Malaysian TVET and offers practical insights for policymakers, curriculum developers, teacher educators, and TVET institutions in strengthening digital readiness, informing competency framework development, and guiding future professional development initiatives.

Keywords: Digital Competency, Robotics Education, Technical and Vocational Education and Training (TVET), Teacher professional development; Robotics integration, Malaysia

Introduction

The rapid advancement of Industry 4.0 technologies has transformed the landscape of Technical and Vocational Education and Training (TVET), particularly through the increasing application of robotics, automation, artificial intelligence, the Internet of Things, and other digital technologies in educational and industrial environments. As industries progressively adopt automated, interconnected, and data-driven production systems, TVET institutions play an important role in preparing learners with the knowledge, technical skills, and digital competencies required for contemporary workplaces. In Malaysia, the development of a highly skilled and industry-responsive TVET workforce has become increasingly important in addressing technological transformation and changing labour-market requirements. Recent Malaysian research highlights the importance of strengthening TVET workforce capabilities, industry alignment, and institutional capacity to ensure that TVET remains responsive to technological and economic changes (Abd Rahman et al., 2025; Mohd Rokeman & Che Kob, 2025). Therefore, strengthening the capacity of TVET institutions and educators to integrate emerging technologies such as robotics into teaching and learning is increasingly important for maintaining the relevance and quality of TVET provision.

Robotics integration is particularly significant within TVET because it provides opportunities for learners to acquire practical and industry-relevant competencies through hands-on and experiential learning. Robotics-based learning can expose students to programming, automation, system operation, troubleshooting, problem-solving, and interdisciplinary learning activities that reflect the technological demands of contemporary workplaces. The increasing convergence of robotics, artificial intelligence, the Internet of Things, and intelligent educational systems further demonstrate the potential of robotics-related technologies to support innovative learning environments and prepare learners for technology-intensive work settings (Adel, 2024). In the TVET context, such learning experiences can strengthen the connection between theoretical knowledge and practical application while providing opportunities for students to develop technical and problem-solving competencies. Consequently, effective robotics integration can contribute to improving the relevance of TVET curricula and strengthening the alignment between educational outcomes and the competencies demanded by Industry 4.0 workplaces.

However, the effectiveness of robotics integration depends not only on the availability of robotics equipment and technological infrastructure but also on the competencies of educators responsible for implementing these technologies. TVET educators require an appropriate combination of technological, technical, pedagogical, and adaptive competencies to integrate emerging technologies effectively into teaching and learning. These competencies may include digital literacy, technological knowledge, programming and system-operation skills, digital pedagogical knowledge, problem-solving abilities, and the capacity to adapt to emerging technologies. Recent research on Malaysian TVET educators emphasises that digital competence is increasingly important in supporting the digital transformation of TVET and in ensuring that educators can use technology

meaningfully in educational practice (Md Hani et al., 2024; Mohd Rokeman et al., 2024). Similarly, research on TVET teachers in the Industry 4.0 context highlights knowledge, skills, and attitudes as important competency components for enabling educators to respond effectively to technological changes in the industrial sector (Mohd Rokeman & Che Kob, 2025). Without adequate educator competency, investments in robotics equipment and digital infrastructure may not necessarily translate into effective educational practices. Therefore, understanding the digital competency requirements of TVET educators is essential to ensure that robotics technologies are utilised effectively, meaningfully, and sustainably rather than being limited to equipment acquisition or basic technical operation.

The need to examine digital competency for robotics integration is particularly relevant in the Malaysian TVET context because digital transformation involves not only technological adoption but also educator preparedness, professional development, curriculum alignment, institutional capacity, and collaboration with industry. Malaysian research has identified challenges associated with digital competence among TVET educators and emphasised the need for systematic development of educator competencies to support digital transformation (Md Hani et al., 2024; Mohd Rokeman et al., 2024). In addition, recent research on the Malaysian TVET workforce indicates that institutional and systemic factors, including fragmented governance and insufficient industry–education collaboration, can influence the effectiveness of TVET workforce development and alignment with labour-market needs (Abd Rahman et al., 2025). These issues suggest that robotics integration cannot be considered solely as a matter of providing technological equipment. Instead, successful implementation requires educators who are adequately prepared, institutions that provide appropriate support, and curricula that remain aligned with technological and industrial developments.

The examination of digital competency needs for robotics integration is therefore significant for several stakeholders within the Malaysian TVET ecosystem. For TVET educators, identifying the competencies required for robotics integration can support targeted professional development and enhance confidence in adopting emerging technologies for teaching and learning. For students, better-prepared educators may contribute to more meaningful robotics-based learning experiences and the development of competencies relevant to digitally transformed workplaces. For TVET institutions and curriculum developers, evidence concerning educators' digital competency needs can support curriculum enhancement, technology integration, professional development programmes, and institutional planning. For policymakers and teacher educators, such evidence can inform the development of appropriate digital competency frameworks, professional development strategies, and resource allocation. Furthermore, strengthening the alignment between TVET education and industrial technological requirements can benefit industry stakeholders by contributing to the development of graduates who are better prepared for technology-intensive and increasingly automated work environments. Despite the increasing importance of robotics and digital transformation in TVET, a comprehensive understanding of the digital competencies required for effective robotics integration among Malaysian TVET educators remains limited. Existing studies have increasingly examined digital competence, Industry 4.0 readiness, and technology integration among TVET educators; however, these areas have not yet been sufficiently

synthesised specifically from the perspective of robotics integration within the Malaysian TVET context (Md Hani et al., 2024; Mohd Rokeman et al., 2024; Mohd Rokeman & Che Kob, 2025). This indicates a need to synthesise available evidence to determine the digital competencies most relevant to robotics integration, the challenges that may affect implementation, and the professional development and institutional support required to facilitate effective adoption.

Therefore, this narrative review aims to explore and synthesise the digital competency needs associated with robotics integration in Malaysian TVET education. Specifically, the review examines the digital competencies expected of TVET educators, identifies challenges affecting robotics implementation, and considers the implications for professional development, curriculum development, institutional readiness, and policy. By synthesising the available literature, this review seeks to provide an integrated understanding of the competencies and supporting conditions required for effective and sustainable robotics integration in Malaysian TVET. The review is expected to contribute to the strengthening of TVET educator development and provide evidence to support Malaysia's efforts to prepare learners for the technological demands of the digital economy and Industry 4.0.

Methods

This narrative review was conducted to explore the digital competency needs associated with robotics integration in Malaysian Technical and Vocational Education and Training (TVET) institutions. A comprehensive literature search was performed using several electronic databases, including Scopus, Web of Science, Google Scholar, ERIC, and ScienceDirect. Additional relevant articles were identified through manual searches of reference lists from selected studies to ensure broader coverage of the topic and to capture influential publications not retrieved during the initial database search.

The literature search was conducted using combinations of keywords and Boolean operators, including "digital competency," "digital skills," "robotics integration," "educational robotics," "Industry 4.0," "TVET education," "technical and vocational education," "Malaysia," "teacher readiness," and "technology integration." Search strings such as ("digital competency" AND robotics AND TVET AND Malaysia) and ("Industry 4.0" AND vocational education AND digital skills) were employed to refine the search process. Only articles published in English between 2019 and 2026 were included to ensure the review reflected current developments related to digital transformation and robotics adoption in education. Peer-reviewed journal articles, conference proceedings, policy reports, and relevant scholarly publications were considered, while non-academic articles, opinion papers, and unrelated studies were excluded. The selection process focused on studies directly related to digital competencies, robotics applications, and TVET education contexts, particularly within Malaysia and comparable educational environments. Studies were included if they discussed digital literacy, technological readiness, robotics implementation, curriculum integration, educator competencies, or Industry 4.0 skills relevant to TVET institutions. Articles lacking relevance to education, robotics, or competency development were excluded. The selected literature was further evaluated based on clarity of objectives, methodological rigor, relevance to the review topic, and contribution to understanding digital competency needs for robotics integration. This

approach ensured that the review remained focused, comprehensive, and aligned with the objectives of the study.

Discussion

Synthesis of Literature

Digital Competency in TVET Education

Digital competency has emerged as a critical component of contemporary Technical and Vocational Education and Training (TVET), particularly within the context of Industry 4.0 and digital transformation. Digital competency encompasses the knowledge, skills, attitudes, and abilities required to use digital technologies effectively and appropriately in educational and professional contexts. For TVET educators, these competencies extend beyond basic digital literacy to include technological knowledge, digital pedagogy, problem-solving, adaptability, and the ability to integrate emerging technologies into teaching and learning (Md Hani et al., 2024; Mohd Rokeman et al., 2024).

The literature further indicates that TVET educators require a broad combination of technical and digital competencies to respond effectively to the changing demands of Industry 4.0. These competencies include the ability to use digital technologies, understand emerging technological developments, solve technology-related problems, and adapt teaching practices to digitally transformed learning environments (Mohd Rokeman et al., 2024; Mohd Rokeman & Che Kob, 2025). This broader understanding is particularly relevant to robotics integration because robotics-based education requires educators to combine technological knowledge with pedagogical strategies and practical skills.

However, the literature also indicates that digital competency is conceptualised differently across studies. Some studies emphasise technical and operational skills, whereas others adopt broader perspectives that incorporate pedagogical, cognitive, collaborative, and adaptive competencies. This variation suggests that digital competency should not be understood solely as the ability to operate digital devices or robotics equipment. Instead, it should incorporate the capacity to select, apply, integrate, evaluate, and adapt technologies according to educational objectives and workplace requirements (Md Hani et al., 2024; Mohd Rokeman et al., 2024).

In the Malaysian context, the development of digital competency among TVET educators remains an important concern because the digital transformation of TVET requires educators to continuously update their knowledge and skills. Md Hani et al. (2024) emphasised the need for a structured digital competency model specifically designed for TVET educators, noting that existing general digital competency frameworks may not fully address the distinctive requirements of vocational education. This finding reinforces the need for context-specific approaches to digital competency development, particularly when emerging technologies such as robotics are introduced into TVET education.

Robotics Integration in Malaysian TVET Education

The integration of robotics into education has become increasingly relevant as industries move towards automation, intelligent manufacturing, and human-machine collaboration. Robotics can support practical and experiential learning by exposing learners to programming, automation, problem-solving, system operation, and technology-based

experimentation. A recent review by Adel (2024) demonstrates that robotics, artificial intelligence, and the Internet of Things are increasingly interconnected within smart education environments and can contribute to the development of future-oriented learning experiences. Within TVET, robotics integration can strengthen the connection between theoretical knowledge and practical application. Robotics-based learning enables students to engage with technologies that resemble those increasingly encountered in automated industrial environments. Such learning experiences can support the development of technical competencies while also encouraging problem-solving, adaptability, collaboration, and lifelong learning (Adel, 2024; Mohd Rokeman & Che Kob, 2025).

Nevertheless, the successful integration of robotics depends substantially on educator preparedness. The availability of robotics equipment alone does not guarantee meaningful educational integration. Educators require sufficient technological and pedagogical competencies to design learning activities, operate relevant technologies, troubleshoot problems, and connect robotics applications with curriculum objectives. Malaysian research indicates that TVET educators face challenges in keeping pace with rapidly evolving digital technologies and therefore require structured competency development and professional support (Md Hani et al., 2024; Mohd Rokeman et al., 2024).

Another important consideration is curriculum alignment. Robotics integration should not be viewed simply as the addition of technological equipment to existing programmes. Rather, robotics-related learning should be aligned with curriculum objectives, occupational requirements, practical competencies, and Industry 4.0 expectations. Mohd Rokeman and Che Kob (2025) emphasised the importance of developing TVET teachers' knowledge, skills, and attitudes to respond effectively to the transformative challenges associated with Industry 4.0. This suggests that robotics integration should involve both technical competency and the pedagogical capacity to translate technological knowledge into meaningful learning experiences. Furthermore, robotics education should adopt a balanced competency perspective. Although technical mastery is important, Industry 4.0 environments increasingly require workers who can communicate, collaborate, solve complex problems, adapt to technological change, and engage in continuous learning. Therefore, effective robotics integration in TVET should combine technical and digital competencies with transferable and adaptive competencies.

Educator Readiness and Professional Development

Educator readiness is consistently identified as an important factor influencing the successful integration of emerging technologies in TVET. Rapid technological development requires educators to continuously update their knowledge and skills, while insufficient professional development opportunities may limit their ability to integrate technologies effectively. Malaysian research has highlighted the importance of developing structured digital competency among TVET educators to support the effective integration of digital technologies into teaching and learning (Md Hani et al., 2024).

Professional development should therefore extend beyond short-term training focused solely on equipment operation. Educators require opportunities to develop technical knowledge, digital pedagogical skills, problem-solving abilities, and confidence in applying emerging technologies. Mohd Rokeman et al. (2024) highlighted the importance of addressing

challenges associated with digital competence among TVET educators, while Mohd Rokeman and Che Kob (2025) emphasised the importance of knowledge, skills, and attitudes in preparing TVET teachers for Industry 4.0.

A sustainable professional development approach may therefore involve continuous training, practical workshops, mentoring, peer learning, industry collaboration, and opportunities for educators to apply new competencies in authentic teaching contexts. Such approaches are particularly important for robotics because educators may need to develop both technical competencies and pedagogical strategies for incorporating robotics into curriculum-based learning activities.

Educator attitudes and confidence should also be considered as part of readiness. Digital competency is not limited to what educators know or can technically perform; their willingness and confidence to adopt emerging technologies may influence how consistently these technologies are incorporated into teaching. Consequently, professional development programmes should address technical skills alongside confidence, motivation, adaptability, and pedagogical beliefs.

Infrastructure and Institutional Challenges

Although educator competency is important, effective robotics integration also depends on institutional readiness and supporting infrastructure. Robotics-based education generally requires appropriate hardware, software, connectivity, laboratory facilities, technical support, and maintenance. Consequently, technology integration should be considered as an institutional process rather than solely an individual educator responsibility. The Malaysian TVET context presents an additional challenge because institutions may differ in terms of technological resources, educator expertise, industry linkages, and institutional capacity. Recent literature on Malaysian TVET highlights broader systemic and institutional challenges affecting the development of a responsive TVET workforce, including governance structures and the alignment between education and industry requirements (Abd Rahman et al., 2025). These issues are relevant to robotics integration because successful implementation requires coordination between educators, institutional leadership, curriculum developers, policymakers, and industry partners.

Institutional leadership also plays an important role in creating an environment that supports technology adoption. Effective leadership can facilitate professional development, resource allocation, industry collaboration, and curriculum innovation. Conversely, limited planning and insufficient technical support may result in robotics equipment being underutilised or used primarily for basic demonstration rather than integrated learning. Another important issue is the sustainability of robotics infrastructure. Investment should not be limited to the initial acquisition of equipment. Institutions also need to consider maintenance, software updates, technical support, replacement costs, educator training, and long-term utilisation. Therefore, institutional planning for robotics integration should incorporate both technological acquisition and sustainability mechanisms.

Implications for Policy, Practice, and Future Research

The reviewed literature suggests that effective robotics integration in Malaysian TVET requires a holistic approach to digital competency development involving educators,

students, institutions, industry, and policymakers. Evidence from Malaysian TVET research indicates that educator digital competency is an important foundation for effective technology integration and that competency development should be aligned with the specific characteristics and requirements of TVET education (Md Hani et al., 2024; Mohd Rokeman et al., 2024).

From a policy perspective, there is a need to strengthen competency frameworks that reflect the technological and pedagogical requirements of Industry 4.0. Such frameworks should recognise that robotics integration requires more than technical operation skills. They should encompass digital literacy, technological knowledge, digital pedagogy, problem-solving, adaptability, collaboration, and continuous professional learning. The development of a context-specific digital competency framework for TVET educators could therefore provide a useful basis for identifying professional development priorities and evaluating educator readiness.

For practice, TVET institutions should adopt professional development strategies that combine technical robotics training with pedagogical application. Training programmes should provide educators with opportunities to operate robotics systems, develop learning activities, troubleshoot technical problems, and connect robotics applications with curriculum outcomes. Stronger collaboration between TVET institutions and industry could further enhance the relevance of professional development and provide educators with exposure to current industrial technologies and practices. Institutional support is equally important. Investment in robotics should be accompanied by adequate infrastructure, maintenance systems, technical assistance, professional development, and curriculum planning. Such an integrated approach can reduce the risk of technology being acquired without being effectively utilised in teaching and learning.

Future research should investigate digital competency for robotics integration using empirical studies involving Malaysian TVET educators. In particular, future studies could examine the specific competency domains and elements required for robotics integration, assess educators' current competency levels, identify competency gaps, and determine appropriate professional development priorities. Longitudinal studies could also examine how educators' digital competency develops following targeted training and how such development influences the quality and sustainability of robotics-based teaching practices.

Overall, the literature indicates that robotics integration in Malaysian TVET should be understood as a multidimensional educational transformation rather than simply a technological adoption process. Effective integration requires the alignment of educator competencies, curriculum, infrastructure, institutional support, professional development, and industry requirements. Addressing these interconnected factors may strengthen the capacity of Malaysian TVET institutions to prepare educators and learners for increasingly automated and digitally transformed workplaces.

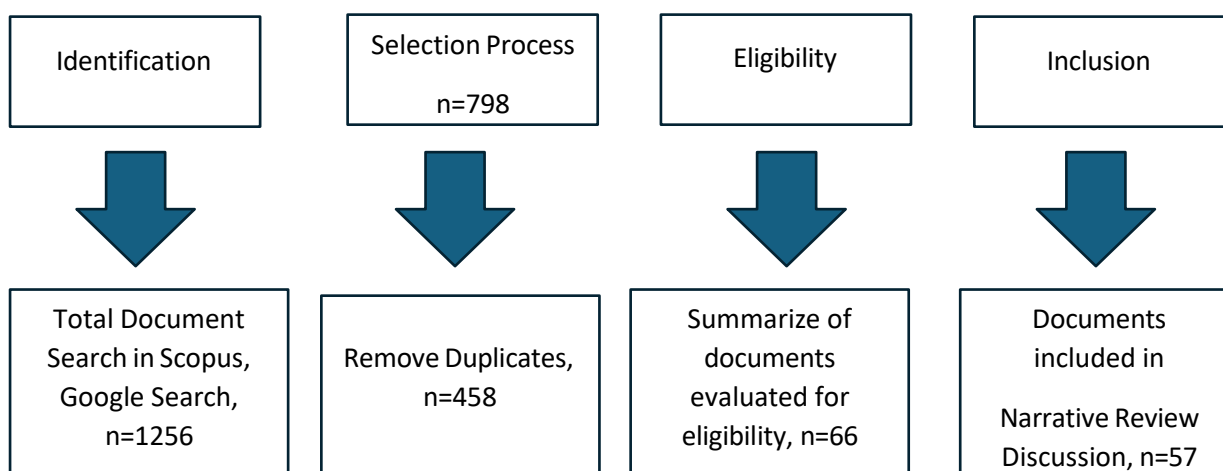
Limitations

Figure 1. PRISMA 2020 flow diagram illustrating the literature search and study selection process for the narrative review. Several limitations should be considered when interpreting the findings of this narrative review on digital competency needs for robotics integration in Malaysian TVET education. First, the review adopted a narrative rather than a systematic review approach, which may increase the possibility of selection bias and subjective interpretation of the literature. Although multiple electronic databases were searched and reference tracking was conducted to improve comprehensiveness, the absence of a rigid systematic protocol means that some relevant studies may have been unintentionally omitted. Furthermore, the review primarily included English-language publications published between 2019 and 2026, potentially excluding valuable studies published in other languages or prior to the selected timeframe.

Another limitation relates to the nature and quality of the available evidence. Existing literature on robotics integration and digital competency in Malaysian TVET education remains relatively limited and fragmented. Many studies focused broadly on Industry 4.0 readiness or digital transformation without specifically examining robotics-related competencies. Additionally, several studies employed small sample sizes, institution-specific contexts, or descriptive research designs, limiting the generalizability of findings across the broader Malaysian TVET system. The heavy reliance on cross-sectional and self-reported data in many studies may also introduce response bias and reduce the reliability of conclusions regarding actual competency levels and technology readiness.

The synthesis process itself presented several challenges. Variations in terminology, competency frameworks, and definitions of “digital competency” across studies created difficulties in comparing findings consistently. Some researchers emphasized technical competencies such as programming and robotics operation, whereas others incorporated broader competencies including communication, collaboration, and digital pedagogy. This lack of conceptual consistency complicated efforts to establish a unified understanding of competency requirements for robotics integration. Moreover, differences in institutional settings, educational levels, and technological infrastructure further limited direct comparisons between studies. Potential publication bias should also be acknowledged, as studies reporting positive outcomes of robotics integration and digital technology adoption are more likely to be published than studies reporting negative or inconclusive

findings. In addition, rapidly evolving technologies associated with Industry 4.0 may cause some reviewed evidence to become outdated quickly, particularly in areas involving artificial intelligence, automation, and robotics applications in education.

Future research should address these limitations by conducting more empirical and longitudinal studies examining digital competency development among Malaysian TVET educators and students. Systematic reviews and meta-analyses may provide more rigorous evidence synthesis and reduce subjectivity in study selection and interpretation. Researchers should also consider developing standardized digital competency frameworks specifically tailored to robotics integration in TVET contexts. Greater attention should be given to underrepresented institutions, rural educational settings, and interdisciplinary competency development to provide a more comprehensive understanding of robotics readiness within Malaysia's evolving TVET ecosystem.

Conclusion

This narrative review explored the digital competency needs required for effective robotics integration in Malaysian Technical and Vocational Education and Training (TVET) institutions by synthesizing current evidence on competency frameworks, educator readiness, curriculum development, institutional challenges, and policy directions. The review demonstrates that digital competency extends beyond technical proficiency to include digital literacy, problem-solving, critical thinking, collaboration, and pedagogical skills necessary for implementing robotics-based teaching and learning. Although robotics integration offers significant potential to enhance students' employability and support Malaysia's Industry 4.0 agenda, the literature consistently identifies challenges related to inadequate educator preparedness, uneven technological infrastructure, fragmented curriculum implementation, and the absence of standardized competency frameworks. These findings directly address the review objective of identifying the digital competencies required to facilitate successful robotics integration and reveal substantial gaps in empirical research focusing specifically on Malaysian TVET contexts. The synthesis further highlights the need for coordinated efforts among policymakers, educational institutions, and industry partners to strengthen digital competency development through continuous professional training, curriculum enhancement, and equitable technological investment. Future research should prioritize longitudinal and intervention-based studies to evaluate the effectiveness of digital competency frameworks and robotics integration strategies, while also developing a nationally relevant competency framework tailored to Malaysian TVET education. Such initiatives would strengthen evidence-based practice, improve workforce readiness, and support the sustainable digital transformation of Malaysia's TVET ecosystem.

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