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TEACHING STEM WITH MEANING: DIGITAL PEDAGOGICAL PRACTICES IN MALAYSIAN TVET

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ABSTRACT

Science, Technology, Engineering, and Mathematics (STEM) education is widely acknowledged as a key driver in developing a skilled and adaptable workforce, particularly within Technical and Vocational Education and Training (TVET). In Malaysia, policy initiatives have increasingly emphasised the integration of digital technologies into STEM teaching. Nevertheless, how such integration is practised pedagogically by TVET educators remains underexplored, especially at the level of everyday classroom practice. This study seeks to examine how STEM pedagogy is understood and implemented through digital technologies by Malaysian TVETMARA educators. Guided by the Technological Pedagogical Content Knowledge (TPACK) framework, the study adopted a qualitative case study approach. Data were gathered through semi-structured interviews, classroom observations, and lesson plan analyses involving ten educators from diverse engineering disciplines across TVETMARA institutions. The data were analysed thematically to capture recurring patterns in pedagogical reasoning and instructional decision-making. The findings indicate five interrelated pedagogical practices: the use of digital technologies to support meaningful learning and understanding; interdisciplinary integration across STEM domains; hands-on inquiry-based learning situated in real-world problem contexts; collaborative engagement among peers and learners; and lesson preparation that is closely aligned with industry standards and workplace expectations. Collectively, these practices highlight that digital technologies are employed not as isolated tools, but as integral components of context-sensitive STEM teaching. The study suggests that effective STEM pedagogy in TVET extends beyond access to digital tools, requiring educators to align technological use with pedagogical intent, disciplinary knowledge, and vocational realities. The findings offer reflective insights for curriculum development, teacher education, and policy initiatives aimed at strengthening STEM practices in vocational education.

Keywords: STEM pedagogy, TVET, digital technologies, TPACK

INTRODUCTION

The growing emphasis on Science, Technology, Engineering, and Mathematics (STEM) education reflects global concerns about workforce preparedness in an era characterised by rapid digitalisation and technological convergence. Within Technical and Vocational Education and Training (TVET), STEM education plays a pivotal role in equipping learners with industry-relevant competencies, such as problem management, adaptability, and technological fluency, required for success in a dynamic labour market(Fadhilah Jamaluddin et al., 2025; Giang et al., 2024; Kamaruzaman et al., 2025). Recent studies continue to highlight the role of digital technologies—such as simulations, virtual laboratories, and collaborative platforms—in supporting applied and experiential STEM learning that mirrors workplace practices(Hubal et al., 2024; Ismail et al., 2025; Sriboonruang & Somsaman, 2025).

In the Malaysian context, national policy directions have increasingly foregrounded digitally enabled STEM education as central to economic sustainability and talent development. Beyond the Malaysia Education Blueprint (2013–2025) and MyDigital, recent initiatives such as the National TVET Policy 2030, the Malaysia Digital Economy Blueprint updates, and the Higher Education Digital Transformation Plan (2023–2027) signal a renewed emphasis on digitally competent graduates who are able to integrate knowledge across disciplines and contexts(Economic Planning Unit, 2024; Foi & Teah, 2022; Idris et al., 2023). These initiatives reflect a shift from access-driven digitalisation towards pedagogically meaningful technology use, particularly within vocational and technical education.

Despite these policy commitments, industry feedback within the Malaysian context continues to point to gaps between graduate capabilities and workplace expectations, particularly in applied problem solving, interdisciplinary thinking, and digital competency. Reports and empirical studies on Malaysian TVET and higher education graduates indicate that employers remain concerned about graduates' readiness to apply knowledge in real work settings, adapt to evolving technologies, and integrate skills across domains (Abd Hamid et al., 2023; Ismail et al., 2025). This suggests that policy aspirations for digitally enabled STEM education have yet to be consistently translated into pedagogical practices that fully meet industry needs.

Furthermore, much of the existing literature on STEM in TVET has focused on curriculum structures, infrastructure readiness, or student outcomes (Agyei et al., 2022; Desai & Kulkarni, 2022). Comparatively fewer studies have examined educators' pedagogical reasoning, how teachers make sense of STEM integration, select digital tools, and align teaching practices with both disciplinary demands and industry realities (Suhirman & Prayogi, 2023; Waters & Orange, 2022; Williams et al., 2019). This gap is particularly significant in TVET settings, where teaching is shaped by certification requirements, institutional norms, and workplace alignment.

STEM pedagogy in TVET is inherently interdisciplinary and practice-oriented, often implemented through inquiry-based, project-based, and design-based learning approaches situated in authentic problem contexts (Elías et al., 2022; Naidoo & Singh-Pillay, 2020; Nurtanto et al., 2020). Understanding how educators navigate the interaction between content, pedagogy, and technology therefore requires an analytical framework that recognises this complexity. Figure 1 presents the Technological Pedagogical Content Knowledge (TPACK) framework, which provides a well-established lens for examining how educators integrate

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content knowledge, pedagogical approaches, and digital technologies in coherent and meaningful ways. Originally articulated by Mishra and Koehler (2006), the framework extends Shulman's (1986) concept of Pedagogical Content Knowledge by explicitly foregrounding the role of technology in teaching and learning. This extension underscores the dynamic relationships between what teachers know, how they design learning experiences, and the technological tools they employ in practice. In particular, the development of Technological Pedagogical Knowledge (TPK) and Technological Content Knowledge (TCK) enables educators to select and use digital tools in ways that are pedagogically purposeful and aligned with disciplinary demands, rather than as isolated instructional add-ons (Koehler & Mishra, 2009; Mishra, 2019; Mishra & Koehler, 2006).

Other studies have further enriched the TPACK framework by emphasising the importance of Contextual Knowledge (XK), which encompasses the institutional, cultural, and infrastructural conditions shaping teaching practice (Brianza et al., 2022; Hafiz Salleh et al., 2022; Phillips, 2016; Swallow & Olofson, 2017). This contextual dimension is particularly salient in TVET settings, where educators must negotiate curriculum standards, resource constraints, certification requirements, and industry expectations. Drawing on this expanded conception of TPACK, the present study examines how TVET educators navigate the interplay between content, pedagogy, technology, and context in their STEM teaching. By foregrounding educators' pedagogical practices, the study aims to generate insights that can inform curriculum development, teacher education, and policy initiatives within vocational education.

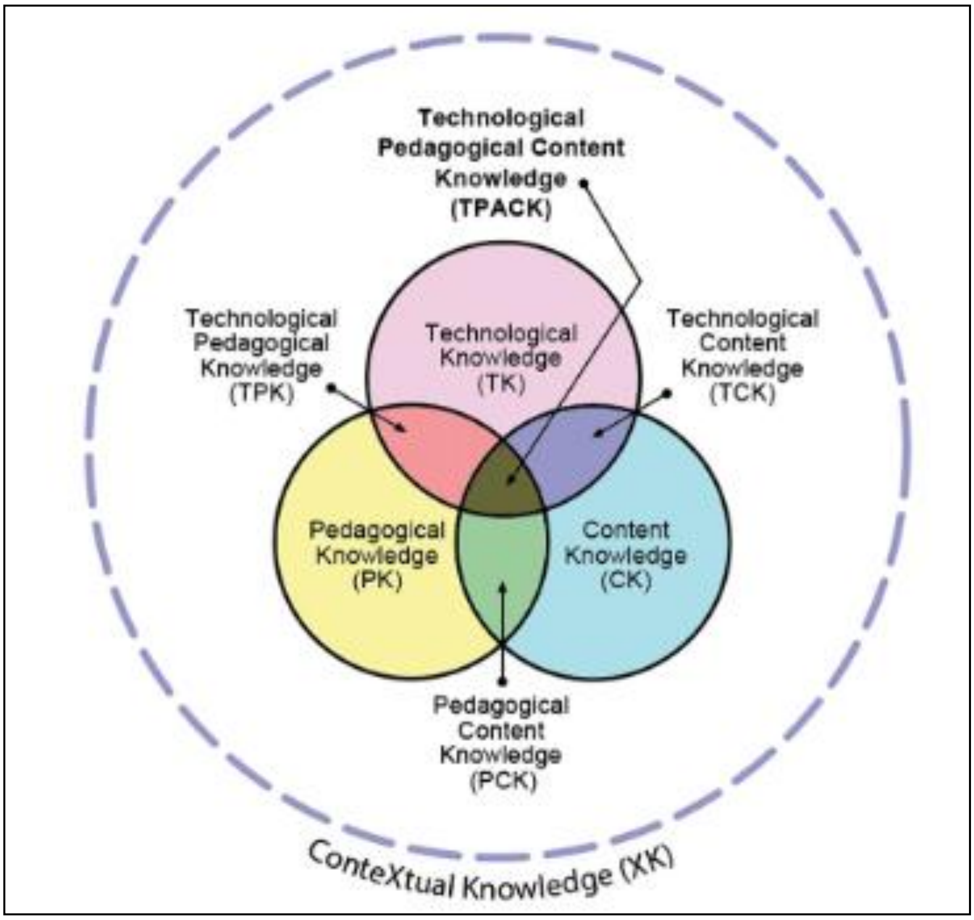

Figure 1. TPACK upgraded diagram (Mishra, 2019).

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METHODOLOGY

Context of the Study

This study was situated within TVETMARA, one of Malaysia's major private providers of Technical and Vocational Education and Training. TVETMARA comprises ten Kolej Kemahiran Tinggi MARA (KKTM), the MARA Japanese Industrial Institute (MJII), and fourteen Institut Kemahiran MARA (IKM) campuses distributed across the country. As a whole, these institutions are characterised by a strong emphasis on hands-on and work-based learning (WBL), where classroom instruction is closely integrated with authentic technical practice.

Across engineering-related programmes, the curriculum is deliberately structured to prioritise practical competence, with approximately 60% to 70% of instructional time devoted to skills-based training and the remaining 30% to 40% allocated to theoretical foundations. In addition, students undertake extended periods of industrial training ranging from 12 to 26 weeks, depending on programme specialisation. This structure reflects TVETMARA's commitment to producing graduates who are technically competent and industry-ready.

TVETMARA's pedagogical approach further incorporates the use of digital technologies and STEM-oriented teaching practices guided by the *Standard Amalan Pendidik MARA* (SPMa). These features, together with the institution's strong industry alignment, make TVETMARA a particularly appropriate context for examining how digital technologies are integrated into STEM pedagogy in vocational education.

Research Design

This study employed a qualitative case study design to explore how Malaysian TVET educators integrate digital technologies into their STEM pedagogical practices. A case study approach is particularly well-suited for investigating contemporary phenomena within real-world educational contexts where boundaries between phenomenon and context are blurred(Brod et al., 2009; Leech & Onwuegbuzie, 2007; Yin, 2018). It enables an in-depth understanding of complex instructional processes and the contextual factors that influence them (Merriam, 1998). Rooted in the TPACK framework, the research aimed to uncover the contextual and instructional realities shaping digital integration within STEM teaching in TVETMARA institutions.

Participants were selected through purposive sampling based on their active use of digital in teaching technical and engineering subjects. Table 1 shows a total of ten educators from various TVETMARA campuses across East and West Malaysia participated in the study. Data was collected through semi-structured interviews, supported by classroom observations and lesson plan analyses, allowing for triangulation and deeper insight into educators' practices.

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Table 1. Demographic Information of Participants

Pseudonym	Age	Subject Matter Expert	Education Level	Teaching Experience
X1	36 yrs	Automotive engineering	Diploma	11 yrs
X2	43 yrs	Electrical engineering	Diploma	14 yrs
X3	37 yrs	Electrical engineering	Master (phd student)	11 yrs
X4	44 yrs	Machine building maintenance and technology	Degree	8 yrs
X5	43 yrs	Electrical and electronic engineering	Master	13 yrs
X6	39 yrs	Electrical engineering	Diploma	17 yrs
X7	44 yrs	Civil engineering	Master	17 yrs
X8	38 yrs	Electrical engineering	Master	11 yrs
X9	48 yrs	Automotive engineering	Master	20 yrs
X10	46 yrs	Mechanical engineering	Master	20 yrs

The interview protocol was developed through expert review and informed by the core domains of the TPACK framework, ensuring attention to technological, pedagogical, content, and contextual knowledge. Classroom observations were conducted using a structured checklist adapted from TPACK-informed frameworks and the *Standard Amalan Pendidik MARA* (SPMa), while lesson plans were analysed using a rubric designed to examine the coherence between content, pedagogy, and technology.

Data were analysed thematically following Braun and Clarke's (2006) six-phase approach. Qualitative data were systematically coded and organised using Quirkos software to support transparency and analytic rigour (Braun & Clarke, 2006; Clarke & Braun, 2017). This process led to the identification of five interrelated themes that characterise digitally supported STEM pedagogy in TVETMARA: digitally enhanced teaching practices, interdisciplinary integration, hands-on inquiry-oriented learning, collaborative peer engagement, and authentic lesson preparation aligned with industry expectations. The five themes illustrate the situated nature of STEM teaching within the TVET context and underscore the role of institutional and infrastructural conditions in shaping digital pedagogical practices.

RESULTS

Analysis of the interview, observation, and document data revealed five interrelated pedagogical themes that characterise digitally supported STEM teaching in TVETMARA: (1) digitally enhanced pedagogical practices, (2) interdisciplinary delivery and integration, (3) hands-on inquiry-based learning, (4) collaborative peer engagement, and (5) authentic lesson preparation aligned with industry needs.

Digitally Enhanced Pedagogical Practices

TVETMARA educators made purposeful use of digital technologies to support learning, particularly in facilitating conceptual understanding, visualisation, and formative assessment

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in technical and engineering subjects. Digital tools were not treated as supplementary add-ons but were embedded across different stages of teaching to support explanation, demonstration, practice, and feedback.

Interview data indicated that educators selected digital tools based on their relevance to subject content and their capacity to engage learners. Commonly used technologies included design software (e.g., AutoCAD, SketchUp), simulation platforms (e.g., Arduino, MATLAB), multimedia resources, and cloud-based platforms such as Google Classroom and Microsoft Teams. These tools enabled educators to illustrate complex engineering concepts, stimulate discussion, and connect theoretical knowledge with real-world applications.

Classroom observations corroborated these accounts. Educators used video demonstrations to explain mechanical processes, real-time platforms such as ThingSpeak to visualise IoT data, and interactive questioning during digital presentations to support understanding. Lesson plan analysis further confirmed the systematic integration of digital technologies across instructional phases, including content introduction, guided practice, assessment, and collaborative activities. Overall, digitally enhanced pedagogical practices in TVETMARA were characterised by strategic tool selection, emphasis on visualisation, and learner engagement aligned with the demands of contemporary vocational education.

Interdisciplinary Delivery and Integration

STEM teaching in TVETMARA was strongly characterised by interdisciplinary integration, particularly across engineering, technology, and mathematical reasoning. Educators consistently emphasised the importance of designing learning activities that mirror the complexity of workplace tasks, where disciplinary boundaries are rarely isolated.

Interview data revealed that educators deliberately combined concepts from multiple STEM domains when designing problem-solving activities. For example, participants described projects that required students to apply engineering theory, mathematical reasoning, and digital tools such as AutoCAD to simulate mechanical systems, reflecting authentic industry practices.

These approaches were evident in classroom observations, where interdisciplinary learning was enacted through the use of tools such as Arduino, MATLAB, and Microsoft Project to integrate coding, electronics, data analysis, and design processes within a single task. Lesson plans further illustrated this integration. In LP4, students explored material properties through the combined lenses of chemistry, physics, and engineering, while LP2 required students to apply theoretical design principles using AutoCAD. Such practices enabled students to make meaningful connections across disciplines and contextualise STEM knowledge within real-world engineering applications.

Hands-on Inquiry Based Learning

Hands-on inquiry-based learning emerged as a central feature of STEM pedagogy in TVETMARA. Educators structured lessons around open-ended tasks that encouraged exploration, experimentation, and iterative problem solving, often supported by digital tools.

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Interview data highlighted the use of multimedia resources and simulations to support inquiry. For instance, one educator used video demonstrations of automotive components as a starting point for student-led reassembly tasks, while others employed 3D simulations and videos to support understanding of pneumatic systems and material processing. These strategies enabled students to visualise industrial processes and engage actively with technical concepts.

Observations showed that inquiry was supported through scaffolding and guided discussion, with educators encouraging students to ask questions, test ideas, and refine solutions. In IoT-related classes, simulators such as Arduino and MATLAB allowed students to explore technical applications at their own pace. Lesson plans reflected this inquiry orientation, with structured problem-based learning activities that guided students from conceptual understanding to practical application using industry-standard tools.

Collaborative Peer Engagement

Collaborative peer engagement played a significant role in supporting both teaching and learning in digitally mediated STEM environments. Educators viewed collaboration as essential for reflecting workplace practices and managing the complexities of digital integration.

Interview data revealed that educators frequently relied on peer networks to share digital tools, teaching strategies, and technical solutions. Several participants described colleagues as important sources of support in experimenting with new technologies and refining lesson designs. Cross-disciplinary collaboration was also evident, with some educators leading workshops to support peers from different engineering departments.

Classroom observations showed that collaboration was embedded in teaching practices through group-based tasks, peer assistance, and shared problem solving using digital platforms such as Microsoft Teams and Google Meet. Lesson plan analysis and institutional documentation further indicated that educators shared teaching materials through cloud-based repositories, enabling reuse and adaptation across campuses. Collaboration also extended to technical staff and students, with some educators forming support groups to address technical issues and identifying digitally proficient students to assist their peers.

Authentic Lesson Preparation Aligned with Industry Needs

Authentic lesson preparation aligned with industry expectations emerged as a defining feature of STEM teaching in TVETMARA. Educators consistently emphasised the importance of aligning lesson content with syllabus requirements, certification standards, and workplace practices.

Interview and observation data showed that educators planned lessons carefully to ensure coherence between learning outcomes, instructional activities, and industry relevance. Lesson sequencing, pacing, and scaffolding were designed to support students' readiness for industrial training. In observed classes, educators framed theoretical concepts through workplace scenarios and used digital tools such as simulations and data visualisation platforms to illustrate real engineering applications.

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Lesson plans provided further evidence of this alignment. Instructional sequences were structured around practical challenges, with digital tools used to enhance understanding and application of complex content. Platforms such as Microsoft Teams and WhatsApp were used to extend learning beyond class time, facilitating access to resources, discussion, and feedback. Collectively, these practices demonstrate how TVETMARA educators integrate curriculum goals, digital technologies, and industry expectations to support meaningful STEM learning.

DISCUSSION

This study examined how Malaysian TVET educators integrate digital technologies into STEM pedagogical practices and identified five interrelated themes: digitally enhanced pedagogical practices, interdisciplinary delivery and integration, hands-on inquiry-based learning, collaborative peer engagement, and authentic lesson preparation aligned with industry needs. Collectively, the five themes offer a coherent account of how digital pedagogy is practised within the institutional and vocational context of TVETMARA. Viewed through the TPACK framework, the findings reaffirm that technology integration in TVET is best understood as a situated pedagogical process shaped by instructional intent and contextual demands, rather than as a purely technical exercise(Abd Hamid et al., 2023; Jamil et al., 2023).

In particular, digitally enhanced pedagogical practices were evident in educators' deliberate selection of tools that aligned with curriculum goals, content requirements, and learner needs. Platforms such as AutoCAD, IoT simulators, Microsoft Teams, and WhatsApp were employed not only to support content delivery, but also to facilitate assessment, communication, and engagement. From a pedagogical perspective, these practices reflect the core premise of TPACK, namely the dynamic interaction between technological knowledge, pedagogical intent, and subject matter expertise(Koehler & Mishra, 2009b; Mishra, 2019b). More importantly, the findings indicate that effective digital integration was guided by contextualised professional judgement, with educators prioritising pedagogical relevance and industry applicability over technological novelty (Abd Hamid et al., 2023; Ismail et al., 2025). Closely related to this was the theme of interdisciplinary delivery and integration. Educators routinely combined concepts from science, mathematics, engineering, and technology when designing learning activities centred on real-world technical problems. This approach mirrors the nature of workplace tasks and supports students in making meaningful connections across disciplines. In line with recent discussions on STEM and TVET education, such interdisciplinary practices underscore the importance of contextual knowledge in shaping instructional decisions within vocational settings (Brianza et al., 2022; Fadhilah Jamaluddin et al., 2025).

Building on this, hands-on inquiry-based learning emerged as a central pedagogical approach supporting STEM teaching. Educators structured learning experiences around exploration, experimentation, and iterative problem solving, often supported by simulations and scenario-based tasks. The use of IoT platforms and virtual simulations enabled students to engage with technical concepts in ways that closely resembled industrial processes. This suggests that digital tools were most effective when embedded within inquiry-oriented designs that foregrounded learning processes rather than task completion, a pattern also noted in recent STEM research (Deák et al., 2021; Giang et al., 2024; Ješková et al., 2022). In addition, collaborative peer engagement played a critical role in enabling meaningful digital integration. Educators relied on professional collaboration to share resources, address technical challenges,

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and refine pedagogical strategies. Such practices point to a collective approach to managing the complexities of digitally supported STEM teaching and highlight the importance of professional learning communities in strengthening digital pedagogical capacity within TVET institutions (Dayangku Suraya Awang Jafar et al., 2020; Salleh et al., 2021; Valverde-Berrocoso et al., 2021).

Finally, authentic lesson preparation aligned with industry needs was deeply embedded in educators' teaching practices. Lesson plans were deliberately designed to reflect workplace scenarios, certification requirements, and industry-relevant technologies. This alignment ensured that digital tools supported both disciplinary learning and vocational relevance, reinforcing recent Malaysian policy and research that emphasise closer alignment between education, industry, and digital transformation agendas(Hubal et al., 2024; Economic Planning Unit, 2024) .

Taken together, the findings indicate that digital technology integration in STEM teaching within TVET is a highly contextualised and pedagogically driven process shaped by educators' values, industry alignment, and institutional conditions. By foregrounding contextual knowledge alongside technological, pedagogical, and content knowledge, this study extends the application of the TPACK framework—particularly its contextual dimension (Mishra, 2019)—to more accurately capture the realities of STEM pedagogy in vocational education settings such as TVETMARA.

CONCLUSION

This study contributes to a clearer understanding of how digital technologies are integrated into STEM pedagogical practices within Malaysian TVET, using TVETMARA as a focused institutional context. By examining educators' practices through the TPACK framework, the study identified five interrelated pedagogical themes that characterise meaningful digital integration: digitally enhanced pedagogical practices, interdisciplinary delivery and integration, hands-on inquiry-based learning, collaborative peer engagement, and authentic lesson preparation aligned with industry needs.

The findings demonstrate that effective digital integration in TVET is not driven by technology availability alone, but by educators' pedagogical judgement, disciplinary expertise, and sensitivity to vocational and industry contexts. Educators in this study selected and used digital tools in ways that supported learning clarity, practical application, and workplace relevance, highlighting the importance of contextual knowledge in shaping STEM pedagogy. In doing so, the study extends the application of the TPACK framework by foregrounding contextual considerations as a central component of technology-integrated teaching in vocational education.

Overall, this research provides empirically grounded insights into STEM pedagogy within Malaysian TVET and offers a practical contribution to curriculum development, teacher education, and institutional planning. By demonstrating how TVET educators navigate the intersection of technology, pedagogy, content, and context, the study supports ongoing efforts to strengthen digitally enabled STEM education in vocational settings and to better align teaching practices with contemporary industry demands.

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