Exploring ICT Integration Practices in STEM Teaching of TVETMARA Malaysia

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Abstract
STEM education is gaining global recognition because of its crucial role in equipping students with the necessary skills for future professional opportunities. However, the proficiency and skill of educators, including their understanding of STEM disciplines and effective teaching methods, are key determinants of the success of STEM education. Therefore, ICT plays a crucial role in improving teaching and learning methods in STEM education within the TVET platform, ensuring the effectiveness of subject delivery and the relevance of STEM education. This study aims to explore TVETMARA educators' experiences in integrating ICT into STEM teaching through the lens of TPACK. Ten TVETMARA educators participated in semi-structured interviews. Thematic analysis generated five themes: ICT Selection, Organizational Support, Peer Collaboration, Pedagogical Practices, and Lesson Preparation. This study contributes valuable insights to STEM teaching with the inclusion of ICT in the context of TVET.

Keywords: STEM teaching, TVET, ICT, TPACK

1. Introduction

Improving students' preparation for future employment prospects is a global need that requires STEM education. Within various areas, STEM education comprises various educational approaches (Breiner et al., 2012; Gonzalez & Kuenzi, 2012; Jiun Chong, 2019; Kennedy & Odell, 2014; M. Lee et al., 2019). Pedagogical approaches within the field of STEM education include teachers' conceptions of STEM teaching (Pimthong & Williams, 2018), teachers' characteristics of STEM teaching (Bell, 2016; English, 2016; Hu & Garimella, 2014; Wang et al., 2011)), and students' experiences of STEM teaching and learning. STEM education integrates multiple disciplines and goes beyond the teaching of a single discipline. It requires innovative methods of instruction in STEM education (Kelley & Knowles, 2016; Wang et al., 2011), with teachers playing an important role (de Jong, 2019; McConnell, 2017; Srikoom et al., 2018).

In Malaysia, the STEM approach is a critical education component, focusing on students' ability to apply STEM knowledge to solve real-world problems. Technical and Vocational Education and Training (TVET) naturally aligns with this approach by emphasizing creativity and problem-solving skills. The TVET curriculum also encourages students to apply their knowledge across different disciplines, contributing to the development of STEM education (Dixon & Hutton, 2016; Reeve, 2016).

Teachers' understanding and application of STEM Education significantly influence the quality of STEM course delivery (Bell et al., 2017). Research has emphasized the importance of technology in the pedagogical knowledge of STEM educators (Babb et al., 2018; Bell et al., 2017; Novak & Wisdom, 2018; Yildirim & Sidekli, 2017). Educators in Science, Technology, Engineering, and Mathematics (STEM) must have the technical skills to effectively teach their subjects (Goy et al., 2017; Türk et al., 2018). However, studies have found that STEM instructors often lack proficiency in using information and communication technologies (ICT) (Chan & Fitri Suraya, 2019). Furthermore, instructors struggle to fully integrate technology due to a lack of confidence in selecting the most effective teaching methods (Azlida & Abdul Halim, 2017; Singh & Chan, 2014).

2. Literature Review

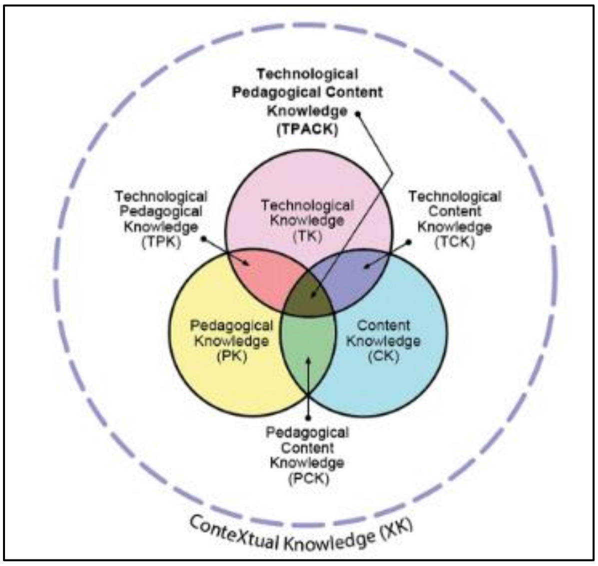
Teaching becomes the focal point (de Jong, 2019; McConnell, 2017; Srikoom et al., 2018) in STEM Education, though teaching is considered as a complex process (Koehler & Mishra, 2009). The importance of STEM education in TVET programs is becoming more widely acknowledged. The notion of "STEM Teaching" refers to the pedagogical approaches used by educators to enhance the comprehensibility of scientific, technological, engineering, and mathematical principles for students. Pedagogical practices in STEM teaching encompass a range of approaches and strategies to enhance students' learning experiences and knowledge acquisition in the fields of Science, Technology, Engineering, and Mathematics. Several studies have explored and highlighted various effective pedagogical practices in STEM teaching. These practices are essential to promote students' engagement, critical thinking, and problem-solving skills, preparing them for future success in STEM-related fields.

One prominent pedagogical practice in STEM teaching involves integrating science, technology, engineering, and mathematics subjects. This approach encourages teachers to design lessons that connect concepts from different STEM disciplines, allowing students to see these subjects' interrelatedness and real-world applications. Integrated STEM education emerges as a crucial and promising approach to equipping students with the skills and competencies necessary to thrive in an ever-changing global landscape .(Kelley & Knowles, 2016; Mustafa et al., 2016; Thibaut, 2018) Past studies (Kelley & Knowles, 2016; Mustafa et al., 2016; Thibaut, 2018) collectively emphasize the urgency and significance of providing students with a robust STEM education. They all recognize the impact of an information-based and technologically advanced society on global security, economic stability, and competitiveness. Each study presents various instructional strategies that promote comprehensive STEM literacy and 21st-century skills, enabling students to excel in a dynamic and technology-driven world.

The term "ICT integration in education" refers to the incorporation of computer-mediated communication into traditional classroom practices. The primary goal of integrating ICT into education is to improve standards by increasing accessibility, user-friendliness, and effectiveness. In their work, Ghavifekr & Rosdy (2015) underscore the vital role of teachers in integrating ICT into their daily classrooms, creating a dynamic and proactive teaching-learning environment. The authors also emphasize the advantages of networking in learning communities as a response to the challenges posed by contemporary globalization. Initially, 'integration' serves as a comprehensive term encompassing various measures teachers take to incorporate ICT, digitalization, or technology into lesson planning. Particularly in the digital age, the integration of technology in STEM teaching is imperative. Technological tools and resources play a crucial role in enhancing students' learning experiences, providing interactive and dynamic learning opportunities. Examples of such tools include simulations, virtual labs, educational software, and multimedia presentations.

Mishra and Koehler (2006) argue that instructors should give significant importance to knowledge requirements regarding the use of technology in their instructional practices. Technology knowledge becomes an essential aspect for teachers as it helps make subject matter more accessible to students through representations, analogies, examples, explanations, and demonstrations. The TPACK framework thus represents content, pedagogy, and technology knowledge as well as the complex interplay of these bodies of knowledge for developing effective teaching using technology (Koehler & Mishra, 2009). Organizing information in teaching and learning of STEM subjects can benefit from incorporating technology (Pringle et al., 2015). Lee et al. (2019) asserts the importance of assessing teachers' ability to integrate Information and Communication Technology (ICT) into their teaching practices to achieve effective STEM teaching (M. Lee et al., 2019). Using the TPACK (Technological Pedagogical Content Knowledge) paradigm, several studies have examined the capacity of teachers to integrate technology into their teaching. Harris and Hofer (2017) discovered that limited research has studied how in-service teachers obtain information within their community of practice (Harris & Hofer, 2017).

Figure 1: Revised Version of TPACK Diagram (Mishra, 2019)



Previous studies have reported how teachers are impacted by contextual elements in the classroom and school environment. Additionally, Rosenberg and Koehler (2015) highlight the importance of contextual factors in the Technological Pedagogical Content Knowledge (TPACK) paradigm. However, there is a need for greater clarity in the context of TPACK research. According to Rosenberg and Koehler (2015), the context involves various settings where technology-aided teaching occurs, including diverse classrooms and school environments. Factors such as subject topic, grade level, student background, available technologies, and societal influences must all be considered. Hence, it is the purpose of this study is to understand the practices of STEM educators in TVETMARA integrating ICT into their STEM teaching from the lens of TPACK.

3. Methodology

The researcher conducted the qualitative phase of the investigation using a case study approach. According to Yin (2018), a qualitative case study involves evaluating a specific, current incident that is constrained by both time and geography (Yin, 2018). This investigation focused on MARA technical institutions (TVETMARA). TVETMARA was selected as a sample example because it is a private Technical and Vocational Education and Training (TVET) provider in Malaysia with extensive and readily accessible data for research. The researcher conducted online interviews with 10 participants of TVET educators throughout East and West Malaysia. Teams were utilized to record the interview sessions. Throughout the interviews, the researcher noted elements indicating the use of ICT in STEM teaching.

3.1 Participants and Sampling

The qualitative case study approach employed a purposeful sampling strategy. This study chose the purposive sampling method because it enabled the researcher to recruit participants who practice ICT integration in their STEM teaching. The sample for this study was TVETMARA educators who met the following criteria:

- Background in Technology and Engineering.
- Have attended pedagogy courses.
- Utilization of ICT (Information and Communication Technology) in teaching and learning, including software/hardware, online learning, simulators, designing tools and Microsoft, Google
- Have participated in any workshops or courses to enhance the use of technology in teaching and learning (external/internal).

The researcher obtained permission from TVETMARA's directors and deputy academic directors to conduct the study, as well as a list of TVETMARA educators who met the criteria for participation in the study. The deputy academic directors aided in the recruitment of educators to engage in the study, and they also allowed the researcher to contact the participants. The researcher scheduled an interview session after receiving confirmation from the educators about their willingness to participate.

Ten TVETMARA educators were chosen from diverse engineering areas, including electrical, automotive, mechanical, and civil. They were in-service TVETMARA educators from East and West Malaysia who held a Vocational Training Certificate (VTO) issued by the Ministry of Human Resources' Department of Skills and Development, as required by ACT 652 (NASDA). Furthermore, using best practices in TVETMARA, they integrated ICT into their STEM teaching. The demographic information of the interview participants was presented in Table 1.

Table 1: Demographic information of interview 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	Degree	8 yrs

		maintenance and technology		
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

3.2 Data Analysis

During the qualitative phase, the researcher began analyzing the data from the semi-structured interview using Braun and Clarke's (2006) Thematic analysis approach. According to Braun and Clarke (2006), Thematic analysis is divided into six stages:

1. **Familiarize with data:** The researcher conducted and transcribed interviews herself as the first stage in becoming acquainted with data. It enabled the researcher to reflect on and become acquainted with the words used by participants while describing how they performed STEM teaching with the integration of ICT.
2. **Generate initial codes:** The generating codes phase included inductive and deductive coding. Before assigning codes and themes, 'toggle notes' were utilized on transcriptions using Quirkos software. For example, using TPACK as the conceptual framework coding ICT selection based on curriculum and teaching methodologies as indicators of ICT integration practices. However, using the participants' words, such as 'practical class,' served as inductive coding.
3. **Look for themes:** In this phase, the researcher looked for patterns of shared meaning in the coded data. For example, under the theme 'ICT selected associated with course outcomes presented,' codes simulator, improved drawing, and sophisticated technology are included.
4. **Review themes:** The researcher incorporated and reflected on the literature to see if the themes convey the substance of the coded data.
5. **Define and identify themes:** Based on step 4, the researcher gave each theme informative and intriguing names.
6. **Write a report:** To verify the final analysis, the researcher selected excerpts from participants and the researcher's interpretation of the literature.

4. Findings

The TPACK theoretical framework guides the entire study and informs the coding and analysis of themes to develop the STEM ICT Teaching Inventory. Five themes on the practices of ICT integration in STEM teaching among TVETMARA educators were generated after analysing and triangulating multiple data sources in the case study, including ten individual interviews, class observations and lesson plan analysis. The five themes are: (1) ICT selection, (2) Organisation support, (3) Peer collaboration, (4) Pedagogical practices and (5) Lesson preparations.

Figure 2: Revised Version of TPACK Diagram (Mishra, 2019)

4.1 Theme 1 : Criteria of ICT Selection

TVET MARA teachers select ICT tools based on their curriculum, which includes engineering design and simulation modeling. Engineering drawing is a crucial tool in designing complex projects, providing accurate and detailed plans for buildings or structures. With the advancement of IR 4.0, ICT plays a crucial role in improving the efficiency of computer-aided design systems. Software like AutoCAD is used in various technical engineering departments, such as automotive engineering, mechanical and electrical engineering, and is used for design and construction. In the interview with TVETMARA educators, engineering drawing is highlighted as one of the main courses taught in various technical engineering departments. For example, in automotive engineering, a TVETMARA educator (X1) shared that :

> *For semester one students, I am teaching them to use AutoCAD software for basic engineering drawings since they are still learning engineering concepts. The name of the course is Engineering Drawing, which helps students produce and interpret production drawings based on standard specifications. Semester 3 students are taught inventor software to upgrade their two-dimensional and three-dimensional drawings.* (X1)

The TVETMARA syllabus provides guidance on software selection for engineering drawing classes, with AutoCAD being used as a teaching aid to visualize designs and simplify the construction of complex structures. TVETMARA educator X6, who has experience teaching mechanical and electrical engineering, illustrates the difference between applying AutoCAD in both fields. He said that:

> *Mechanical engineering uses AutoCAD for design. I taught Marine students in the TVETMARA centre using AutoCAD to draw isometric and two-dimensional displays with the top and back. It is more complicated in the Mechanical field and involves hidden dimensions than in the Electrical field, which is more related to house plans and schematic drawings* (X6).

Simulators are essential tools in the engineering industry for experimentation and providing immediate feedback on performance metrics. TVET educators incorporate simulators as part of their course syllabus, incorporating them as one of the ICT tools in STEM teaching, particularly in practical classes. By doing so, they equip TVETMARA students with the necessary skills and knowledge to succeed in the industry. When asked about the ICT tools used in STEM teaching, X2, a TVET MARA electrical instructor, highlighted the function of having a simulator in the electrical workshop to run experiments. He commented that :

> *For motor control, there is its simulator – a synchronised motor. It means testing the mentioned motor and how fast the speed of the motor is. For example, if we want the motor running at a certain speed, how much volt and ampere should it have? Most of the courses on electric power use simulators*. (X2)

Active teaching strategies are adopted in TVETMARA to promote deeper understanding and high retention of learning materials. These methods include problem-based learning, demonstrations, group discussions, and hands-on activities. TVETMARA educators use video-based, PowerPoint, and online teaching to create a collaborative and supportive learning environment for their students. Videos are also used to showcase technical processes in TVETMARA classes, allowing students to observe, analyze, and replicate tasks in real-time.

One common view shared by interviewees is the use of videos to showcase technical processes. In TVETMARA classes, demonstrations are an active and engaging learning approach that allows students to observe, analyse and replicate tasks in real-time. For example, X1 utilises videos from YouTube to demonstrate tasks such as disassembling car parts. Based on the video, he instructs his students to create their video on assembling car parts, using techniques shown in the video.

In Materials Engineering classes, videos are uploaded to show the processing of raw industrial materials into finished products. Students prefer visual aids that provide a simulation of the process, making videos an effective method for teaching. In hydraulic and pneumatic classes, videos illustrate hydraulic equipment movement in three dimensions, allowing students to observe and discuss from every angle.

TVETMARA educators support the integration of ICT tools in STEM teaching, selecting tools based on the TVEMARA syllabus and active teaching strategies. They ensure that students are equipped with the necessary skills and knowledge in their chosen technical fields by selecting tools such as AutoCAD software for engineering drawing classes and simulators that align with industry requirements.

Incorporating visual aids like videos and PowerPoint presentations into active teaching strategies helps students grasp complex concepts effectively. Online teaching tools like Google Classroom, Teams, and Online Chat enable students to easily access lessons and interact with their educators. Overall, TVETMARA educators advocate for the integration of ICT tools in STEM teaching to ensure students receive comprehensive education and develop their skills in their chosen fields.

Theme 2 : Organisation Support

The qualitative results for Theme 2, Organisational Support, highlighted three aspects: ICT infrastructure adequacy, educational leader support, and professional development ICT training. TVETMARA can help educators overcome the challenges of integrating ICT into STEM teaching by addressing these aspects. The lack of ICT infrastructure can be seen as an obstacle when educators integrate ICT into their teaching. Therefore, the establishment of a suitable information and communication technology (ICT) framework is of utmost importance to enhance the educational experience.

TVETMARA has implemented a Digitalisation Program to support its teaching staff by equipping them with the necessary ICT tools and skills to achieve high-quality education. One key initiative is to increase the number of ICT infrastructures, such as labs and teaching devices, to accelerate the ICT integration process in STEM teaching. TVETMARA is committed to supporting its educators financially and involving them in the decision-making and planning process of the Digitalisation Room.

TVETMARA is committed to financially supporting its educators and involving them in the planning and decision-making processes for the Digitalisation Room. This is an opportunity for TVETMARA educators to have a say in the implementation of ICT tools and to customize their use to satisfy the requirements of STEM education. This is what X2 responded when asked about the assistance he received from TVETMARA:

> *The organization's efforts to digitalize the instruction and learning process can be observed in its digitalisation program. As part of the budget allocation process, we have requested to discuss and propose the instructional devices we require. We have also set up a digitalisation room in my department, utilizing the available space and incorporating new ICT tools.* (X2)

Internet accessibility has become crucial in ICT integration into teaching practices in the evolving digital era of IR 4.0. Insufficient access to the internet can be an obstacle for educators to embrace technological advancements fully. Internet connectivity is still slow to support the seamless use of ICT to facilitate instruction activities. X1 and X5 shared the same view on how internet accessibility affected the effectiveness of ICT integration into STEM teaching. They believe there is sufficient support from the management regarding training or facilities for TVETMARA lecturers, but there is still a lack of ICT infrastructure for students.

Educational leaders at TVETMARA institutions play a crucial role in promoting and facilitating the integration of ICT in classrooms. They provide resources, motivation, and training to TVETMARA educators, encouraging and recognizing their efforts in incorporating ICT in STEM teaching. The leaders also include digital teaching materials in the measurement of key performance indicators (KPI). TVETMARA educators are overwhelmed with keeping up with the latest technologies and techniques, so they must allocate adequate resources and time to the learning process.

However, there is still a need for educators to work on using ICT to enhance their teaching and learning process. Education organizations invest in providing professional development training for educators to incorporate ICT effectively. TVETMARA still lacks practical ICT training in pedagogical support, as demonstrated by X6 who attended various technologies competency training but not the one that supports effective teaching.

AutoCAD software training is another example of TVETMARA educators not receiving practical ICT training in pedagogical support. The organization helps TVETMARA educators enhance their technical drawing skills using software by sending them to training organized by outsourcing. Most TVETMARA educators interviewed showed a strong inclination towards independently discovering and experimenting with ICT tools, valuing freedom and adapting with self-learning to gain proficiency in ICT tools.

Theme 3 : Peer Collaboration

Integrating ICT in STEM teaching can improve learning experiences, but challenges include internet access and insufficient training. TVETMARA educators need to create an appropriate learning environment and utilize peer collaboration for effective ICT technology integration. Knowledge sharing and technical support by non-teaching staff improve ICT skills and contribute to pedagogical development.

During interviews, the majority of participants reported that they learned a great deal from their colleagues, who are regarded as organization experts. Intriguingly, one TVETMARA educator described his colleagues as catalysts who played a vital role in his efforts to effectively integrate ICT into his instruction. He indicated that:

I did not explore on my own; I was assisted by my companions. They acted as catalysts, arousing my interest in the technology to learn more. (X3)

Moreover, collaborative activities such as knowledge sharing enable TVETMARA instructors to share effective teaching techniques and innovative ideas. Through the exchange of ideas and experiences, they can implement effective teaching methods. Consequently, they are able to overcome obstacles. During the challenging pandemic period, for instance, one TVETMARA participant (X8) described receiving assistance from her colleagues. X8 navigated new digital tools, including Google Classroom and Microsoft Teams, to facilitate remote learning as TVETMARA institutions transitioned to online instruction. Recognizing the expertise within her collaborative network, she reached out to her counterparts for assistance. X4 was another educator who shared X8's experience. During the pandemic, she did not undergo any formal training on using Google Classroom during the previous semester.

I was required to independently investigate and sought assistance from my colleagues. They provided me with tremendous assistance, as I lack knowledge of ICT in instructing. (X4)

The second activity of collaboration within the TVETMARA community is receiving technical support from student apprentices and technical teams. Technical support is crucial for educators because it enables them to face technical obstacles, equips them with the necessary skills, and facilitates the effective integration of ICT tools in STEM instruction. Technical support ensures that hardware, software, and network infrastructure are configured and maintained correctly. This includes installing and configuring devices such as computer projectors as well as ensuring a dependable internet connection. Without the appropriate infrastructure, educators may struggle to use ICT tools effectively in the classroom.

Theme 4 : Pedagogical Practices

ICT tools are now an integral part of STEM teaching in TVETMARA technical colleges and institutions (Chan & Fitri Suraya, 2019; Deák et al., 2021; Mumcu et al., 2022). These tools offer dynamic and interactive lessons that engage students in exploration activities and foster a deeper comprehension of workplace scenarios. Participants in TVETMARA emphasize four essential STEM education components: workplace application representation, visual representations, collaboration and communication, and interactive learning (Ibrahim & Pour Rahimian, 2010). TVETMARA participants frequently use CAD software to visualize workplace situations, which provides a digital representation of physical spaces, objects, and processes.

X4, a TVETMARA instructor who specializes in mechanical drawing and design, instructs a CAD course using AutoCAD software. She emphasized the significance of dimensioning accuracy and instructed her students on how to identify potential design flaws in their workshop exercises. She stated:

I am currently teaching a CAD course, focusing on geometrical construction.I emphasize the importance of dimensioning when assigning drawing assignments. My students are expected to implement their knowledge of "fit limit and tolerance" in their workshop exercises. The designers must examine how the components join together and identify any potential design flaws, such as manufacturing issues. (X4)

By emphasizing scientific principles, ICT simulation tools, such as CAD software, improve the design process and demonstrate real-world applications(Ibrahim & Pour Rahimian, 2010; Phanden et al., 2020; Ye et al., 2004) . These instruments aid students in comprehending the applicability of their education and encourage them to apply their knowledge to workplace issues. X7, for instance, utilizes role play in her

Basic Architecture Design course to demonstrate the working relationship between a draftsperson and a client. She employs interactive sessions, role-play projects, and multimedia platforms to evaluate the development of her students, evaluate their comprehension of design concepts, and improve their communication skills.

The example provided by X8 illustrates how visual representations using tools such as PowerPoint and Multisim software improve STEM education in electric circuit classes. Students can comprehend abstract electrical circuit concepts with the aid of visual aids. Simultaneously, the Multisim simulation software provides a visual representation of circuits for modifying parameters and observing corresponding outputs.

The integration of ICT in STEM teaching supports pedagogical practices in a number of ways, including class management skills such as learning management systems (LMS), communication and collaboration, and digital assessment and feedback (Birzina & Pigozne, 2020; Yang & Baldwin, 2020; Zubković et al., 2022). As LMS platforms, TVETMARA participants acknowledged the utility of ICT tools such as Microsoft Teams and Google Classroom. For example, X5 discovered that Microsoft Teams is a useful platform for storing and sharing educational resources with students, which helps educators organize instructional materials efficiently. He structured the slides according to the course syllabus, uploaded them to the Teams platform, and then allowed students to access and view them, including sharing them in class.

Theme 5 : Lesson Preparation

Choices made by educators have a significant impact on the effectiveness of ICT integration in teaching and learning as well as the instructional design of their lessons. Thus, lesson planning becomes a crucial factor in determining the efficacy of ICT implementation in the classroom (Janssen et al., 2019; König et al., 2015). It necessitates an in-depth comprehension of the subject, the individual needs of students, and the availability and functionality of technological tools (Ghavifekr & Rosdy, 2015; Janssen & Lazonder, 2015; König et al., 2022). Educators must adapt their use of technology to various situations and instructional objectives in order to effectively enhance the learning process when integrating technology into the classroom. In addition, teachers' knowledge, beliefs, and classroom performance influence their capacity to successfully incorporate ICT into lesson planning, illustrating a symbiotic relationship between their skills and professional success (Ghavifekr & Rosdy, 2015).

According to this study's qualitative findings, integrating information and communication technology (ICT) into STEM education requires two fundamental activities during lesson planning. These activities include instructional planning and ICT planning for STEM-related teaching aides. Educators are responsible for creating instructional learning activities of high quality through a well-structured lesson plan (Nurtanto et al., 2021; Purwinda Anggrella et al., 2023). Lesson plans serve as an instructional guide for a classroom session by delineating specific learning objectives and related content. This allows for the establishment of measurable student learning outcomes.

In addition, these plans describe the teaching and learning process, including the learning activities and methodologies, as well as the required resources, such as study materials and technology (Janssen & Lazonder, 2015). Therefore, adequate lesson planning is essential for integrating technology into the classroom. Coordination between instructional design and ICT teaching tools is crucial for optimizing technological advances in STEM education.

The majority of interviewees concurred that adequate lesson preparation significantly contributes to the effectiveness of lesson delivery. In addition, a structured lesson plan assists teachers in adapting learning to curriculum content (Purwinda Anggrella et al., 2023). One participant, X5, for instance, emphasized the significance of aligning his slides with the course syllabus in his teaching process. He said that:

As part of my teaching process, I meticulously create slides that correspond to the course outline, as he stated. These transparencies are valuable instructional materials because they provide a comprehensive overview of the topic. To facilitate student access, I upload these instructional materials to Microsoft Teams, our designated academic collaboration platform. (X5)

5. Discussions

In accordance with previous research (Fahadi & Khan, 2022; Hamidah & Fitri Suraya, 2022; Mutanga et al., 2018) , findings in Theme 1 suggest that Technology Knowledge (TK) is the predominant component of the TPACK of TVETMARA educators. In this research, TK is crucial for implementing STEM teaching as a pedagogical practice. It includes operating system and computer hardware knowledge, standard software tools such as word processors, spreadsheets, browsers, and email, and ICT tools that support authentic learning experiences via simulators and virtual reality. ICT is a crucial and significant instrument for enhancing STEM teaching and learning (Zubković et al., 2022). Therefore, teachers must have adequate technology knowledge and abilities to teach and learn STEM effectively (Goy et al., 2017; Türk et al., 2018). By combining it with scientific inquiry to create an effective learning environment, technology knowledge is essential in STEM teaching (Arifin et al., 2020) . In addition, technology knowledge facilitates student learning through the use of visuals, analogies, examples, explanations, and demonstrations (Mishra & Koehler, 2006).

The rapid evolution of ICT tools presents a significant challenge for TVETMARA educators, who must ensure that the tools they use align with the learning outcomes of technical and engineering courses. To effectively address this challenge, educators need to acquire adequate technology content knowledge (TCK) to select and utilize appropriate ICT tools. For example, interviews with educators teaching Computer Aided Design (CAD) revealed the benefits of AutoCAD software for students in creating and analyzing practical drawings. Embracing technology and incorporating it into teaching methods is crucial for students to achieve desired learning outcomes. Additionally, utilizing ICT resources such as simulations and videos allows educators to visually and interactively explain complex technical and engineering concepts, contributing to the development of conducive learning environments.

In theme 2, through the lens of TPACK, the organization provides adequate support for the development of Technological Knowledge (TK) among TVETMARA educators. This is addressed by adequate ICT infrastructure, which lays the groundwork for successful ICT integration in STEM teaching. Increasing the number of laboratories and teaching devices has become an important initiative of TVETMARA for achieving high-quality education and training. This is consistent with a previous study by Salehi and Salehi (2012), which concluded that inadequate technical support, limited Internet access, and ICT were significant barriers impeding teachers from integrating ICT into their teaching. In addition, the Digitalisation Program represents TVETMARA's initiative to equip educators with the required ICT tools and skills (Salehi & Salehi, 2012).

In contrast, allocating funds for new ICT tools and infrastructure enhancements demonstrates an organization's commitment to technology. This also includes specific tools, such as the AutoCAD simulator, as well as the need for regular updates and licensing, demonstrating how the TVETMARA curriculum correlates with Technological Content Knowledge (TCK). This is evident from the nature of the TVET curriculum created by those with a high level of technological competency (Dayangku Suraya Awang Jafar et al., 2020).

Moreover, in Theme Peer Collaboration, collaborative activities and technical support in the TVETMARA community foster the development of TVETMARA educators' TPK, TCK, and TK by facilitating the exchange of knowledge, experiences, and strategies related to technology integration in teaching and learning. It provides a forum for TVETMARA educators to share their knowledge and experiences with various ICT tools (TK) and how these tools can be utilized effectively in TVETMARA curriculum contexts (TCK). This collaboration includes the sharing of instructional materials such as lecture plans, videos, and modules. Sharing these resources fosters a community of TVETMARA educators who collectively enhance their TPK, TCK, and TK skills and teaching quality. This is consistent with a previous study that found a collaborative project led to significant teacher gains in technology skills, new knowledge in the use of simulations in teaching, positive pedagogical changes, and increased content knowledge (Allan et al., 2010), which contribute to professional development (Harris & Hofer, 2017) and the development of innovative teaching practices.

The results of the Theme Pedagogical Practices, when viewed through the lens of Technological Pedagogical Content Knowledge (TPACK), demonstrate how STEM teaching in the TVETMARA setting can be strengthened and enhanced through the use of ICT tools. TPACK is a framework that emphasizes the interplay of three essential components, namely technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK), in order to develop effective teaching practices in which ICT facilitates learning. As envisioned by the TPACK framework, TVETMARA educators in this qualitative study demonstrate the dynamic interplay between technological, pedagogical, and content knowledge. It highlights how the proficient use of ICT tools by educators improves STEM teaching practices, generating engaging and effective learning environments for TVETMARA students. This is demonstrated by the use of various ICT tools, such as CAD software, Microsoft Teams, Google Classroom, and Multisim, to conduct practical simulations, deliver engaging lessons, administer assessments, and facilitate communication in order to enhance STEM teaching. It demonstrates their TPACK through their ability to select, adapt, and utilize these instruments effectively. This contradicts earlier findings that TVET only focuses on TK (Hamidah & Fitri Suraya, 2022) (Hamidah & Fitri Suraya, 2022) and is less essential in PK (Junnaina & Hazri, 2014) (Junnaina & Hazri, 2014) because the TVET curriculum emphasizes machine operations and hands-on activities. Mutanga, Nezandonyi, and Bhukuvhani (2018) also discovered that the majority of engineering lecturers were knowledgeable about the individual components of TPACK, particularly content and technology, but lacked pedagogical knowledge. The findings of this qualitative study provide insights that have not yet been captured by previous quantitative studies. The results suggest that TVETMARA educators incorporated best practices for ICT integration into STEM teaching.

The significant finding in Theme Lesson Preparation is that TPACK and contextual knowledge (XK) play a crucial role in the preparation of lesson plans and teaching aids employing ICT in STEM teaching. Elements of TPACK and XK can aid TVETMARA educators in aligning pedagogical strategies and ICT tools with curriculum goals and learning objectives. Integration of TPACK is evident in the well-structured lesson plan that employs ICT to improve pedagogical practices and effectively deliver TVETMARA curriculum content. This finding is consistent with Janssen and Lazonder's (2015) adaptation of the TPACK framework for designing high school biology lesson plans for preservice and in-service instructors (Janssen & Lazonder, 2015). During class observations, fitness content, pedagogy, and technology knowledge (TPACK) are also demonstrated. This result contradicts the results of Rahmawati, Suryani, Akhtar, and Sukarmin (2001). The study discovered that the lesson plans and lessons implemented by vocational high school teachers in Indonesia lacked TPACK - fitness integration technology in learning with curriculum strategies and objectives (Rahmawati et al., 2021). The discrepancy with the findings can be explained by the fact that the sample of respondents were vocational building engineering instructors who lacked ICT knowledge and utilized technology in vocational education in Indonesia less frequently. TVETMARA educators, on the other hand, are able to weave together content, pedagogy, and technology to create a robust educational experience.

6. Conclusions

Utilizing STEM-related information has become increasingly vital for workplace problem-solving, and technical and vocational education (TVET) stands out as a crucial facilitator in cultivating STEM-related knowledge within an educational context. Students in TVET programs skillfully integrate knowledge across diverse disciplines. Project-based learning (PBL), a prevalent strategy in TVET, is pivotal in advancing STEM education by providing a practical, hands-on approach. The alignment of STEM education with contemporary workplace issues further elevates its relevance, ensuring a seamless integration of theoretical knowledge with real-world applications.

Information and Communication Technology (ICT) is an invaluable tool in STEM teaching, offering robust support for effective instruction. Technology-based tools and resources enhance students' learning experiences and foster interactive and dynamic learning environments. While TVET educators have successfully incorporated ICT into their pedagogical practices, proficiency in both ICT and pedagogy proves essential. Teachers require technological expertise and pedagogical skills to innovate in teaching and learning. The Technological Pedagogical Content Knowledge (TPACK) framework, emphasizing the integration of Content Knowledge, Pedagogical Knowledge, and Technology Knowledge, becomes instrumental for effective teaching in a technology-enhanced learning environment like TVET. This study highlights that educators should not only possess expertise in their subject matter (technical and engineering) and effective teaching methods (STEM teaching) but also the ability to leverage technology (ICT) for enhanced learning. Furthermore, recognizing contextual knowledge significantly contributes to the adept utilization of technology in teaching.

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8. References

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