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# Toward an AI-Ready VR Machine Workshop: Transforming CNC Machining Training in TVET for Industry 4.0

## Abstract

The Fourth Industrial Revolution (IR 4.0) requires innovative teaching approaches in Technical and Vocational Education and Training (TVET). This paper presents the VR Machine Workshop, a digital learning environment designed to introduce measurement concepts and machining fundamentals through an immersive 3D platform. By allowing learners to explore visual representations of precision measurement tools such as vernier callipers, micrometers, and height gauges, the system provides a safe and cost-effective environment for repeated practice while reducing dependency on physical equipment.

The project was piloted with Sijil Kemahiran Malaysia (SKM) Level 3 CNC Machining students using a blended learning approach that combined VR-based training through the Artsteps platform with conventional workshop practice. Results indicate improvements in conceptual understanding, measurement accuracy, and learner confidence, accompanied by higher engagement and sustained learning focus.

At its current stage, the VR Machine Workshop functions as a VR-based instructional environment rather than a fully autonomous artificial intelligence (AI) system. It should therefore be understood as an AI-ready learning approach that demonstrates potential for future integration of intelligent features such as adaptive learning guidance, performance analytics, and personalised learning pathways. The study illustrates how immersive VR environments can support the digital transformation of TVET pedagogy in the Industry 4.0 context.

***Keywords:*** *TVET, Virtual Reality, VR Learning Environment, Artificial Intelligence Readiness, CNC Machining*

## 1 Introduction

The Fourth Industrial Revolution (IR 4.0) has significantly reshaped the nature of work and learning, requiring a workforce that is not only technically competent but also digitally adaptive and innovation-oriented. Within the Technical and Vocational Education and Training (TVET) ecosystem, this transformation calls for the integration of emerging technologies that support new approaches to teaching and learning while preparing students for increasingly digitalised industrial environments.

Machining-based programmes remain fundamental to the manufacturing sector; however, training practices in many TVET institutions still rely heavily on physical workshops and conventional equipment. Although such approaches are essential for hands-on skill development, they also present several persistent challenges. These include high maintenance costs, limited access to equipment, safety considerations, and unequal opportunities for repeated practice among students. As the ratio of learners to machines increases, opportunities for mastery-oriented learning and repeated conceptual reinforcement become increasingly constrained.

In response to these challenges, the VR Machine Workshop was developed as an immersive digital learning environment designed to support the introduction of machining measurement concepts through visual and exploratory learning experiences. The environment presents visual representations of precision measurement tools—such as vernier callipers, micrometers, and height gauges—together with supporting instructional materials including explanatory notes, diagrams, demonstration videos, and guided learning prompts. By exploring these materials within a structured 3D environment, learners are able to develop a clearer conceptual understanding of measurement principles before engaging with physical tools in workshop settings.

Beyond its immediate instructional function, the VR Machine Workshop reflects a broader pedagogical shift toward technology-enhanced learning within TVET. Digital learning environments such as VR-based platforms offer opportunities to expand access to instructional resources, support flexible learning pathways, and enhance learner engagement through immersive visualisation. These approaches align with the growing emphasis on digitalisation and technology integration in vocational education, particularly within Industry 4.0-oriented training systems.

While the current implementation focuses on immersive visualisation and structured instructional materials delivered through the VR platform, the VR Machine Workshop also establishes a foundation for future integration of intelligent educational technologies. In particular, the system is conceptualised as an **AI-ready learning environment**, where future development may incorporate features such as adaptive learning guidance, performance analytics, and personalised learning pathways.

Previous discussions in TVET@Asia have highlighted the increasing importance of digital transformation, simulation technologies, and Industry 4.0-oriented pedagogies in vocational education. Building on this discourse, the present study contributes empirical insights from the Malaysian TVET context by examining how a VR-based learning environment can support measurement tool learning and machining-related knowledge within digitally evolving training systems.

Although the VR Machine Workshop incorporates elements associated with digital learning environments, the current system does not operate as a fully autonomous Artificial Intelligence (AI) platform. Rather, it represents a technology-enhanced learning approach that demonstrates the potential for future integration of intelligent learning features within TVET training environments.

## 2 Objectives and Scope

The primary objective of the VR Machine Workshop project is to introduce Virtual Reality (VR) as an immersive, learner-centred pedagogical innovation that supports measurement tool learning in technical and engineering education, while establishing a foundation for future AI-enhanced learning environments in TVET. Specifically, the project aims to:

1. **Enhance conceptual understanding** of measurement principles and tool functions (vernier callipers, micrometers, height gauges, and dial indicators) through immersive 3D learning visualisations that support clearer interpretation of measurement concepts.
2. **Provide a safe, sustainable, and cost-efficient digital learning environment** that reduces safety risks, material waste, and equipment wear while supporting environmentally responsible training practices.
3. **Encourage autonomous and exploratory learning** by providing visual guidance, embedded learning prompts, and flexible self-paced review of instructional materials that may later evolve into AI-supported adaptive learning systems.
4. **Support Malaysia's TVET Digitalization Roadmap and Industry 4.0 initiatives** by integrating immersive digital learning technologies into skill-based training curricula.
5. **Promote inclusive and sustainable digital learning ecosystems** that enhance accessibility, equity, and continuous innovation in the transformation of TVET pedagogy.

The project targets TVET students, technical instructors, industrial apprentices, and lifelong learners in machining-related disciplines. Its modular design enables integration into blended learning environments and provides potential for future expansion into other technical domains such as welding, automotive, and mechatronics.

## 3 Integration of Industry 4.0 and AI-Driven Technologies

The integration of Industry 4.0 technologies within the VR Machine Workshop aims to modernise technical training approaches in the Technical and Vocational Education and Training (TVET) ecosystem. The platform utilises Virtual Reality (VR) to provide an immersive digital learning environment that supports the teaching and learning of machining measurement concepts.

The VR Machine Workshop was developed using the Artsteps platform, which enables the creation of immersive 3D learning spaces. Within this VR learning environment, instructional materials related to precision measurement tools such as vernier callipers, micrometers, and height gauges are presented through visual explanations, learning notes, and guided information panels. Through this environment, learners are able to explore the displayed tools, access instructional materials, and develop a clearer understanding of measurement concepts before engaging with physical equipment in the actual machining workshop.

This approach supports experiential and self-directed learning, allowing students to revisit learning materials and explore the environment at their own pace. By providing visualisation and contextual explanations within a VR-based learning environment, the VR Machine Workshop helps learners build conceptual understanding while reducing dependency on limited physical workshop resources.

At the current stage, the VR Machine Workshop does not function as a fully autonomous Artificial Intelligence (AI) system. The learning environment primarily delivers structured instructional content through the VR platform rather than automated AI-driven decision-making processes. Therefore, the system should be understood as a technology-enhanced learning environment that utilises VR for instructional delivery.

Nevertheless, the VR Machine Workshop represents an initial step toward the future integration of intelligent technologies in TVET training. With further development, VR-based learning environments such as this may incorporate AI-supported features including adaptive learning guidance, performance analytics, and personalised learning pathways. Such developments could further enhance the effectiveness of immersive learning environments within Industry 4.0-oriented TVET education.

## 4 Methodology

To ensure that the VR Machine Workshop was developed with practical relevance and pedagogical integrity, a user-centred design approach was adopted. This methodology emphasised the active involvement of end users—particularly TVET learners, instructors, and technical practitioners—throughout every stage of the design and development process. By engaging actual users, the project ensured that the VR learning environment reflects authentic machining contexts while addressing real training challenges encountered in technical education.

The development process consisted of several key phases, including needs analysis, VR learning environment design, content development, and usability evaluation. The needs analysis phase involved consultations with machining instructors and students to identify critical skills and measurement procedures that often pose difficulties during conventional workshop sessions. Based on these insights, a VR learning environment was developed using the Artsteps platform, which enables the creation of immersive 3D spaces where visual representations of measurement tools and instructional materials can be organised in an accessible learning format.

The learning design followed a progressive sequence that began with the introduction of theoretical concepts, continued with guided observation of measurement tools and demonstrations, and culminated in self-directed exploration within the VR learning environment. This structure allows learners to review learning materials repeatedly, strengthening their conceptual understanding before performing measurements using physical instruments in the workshop.

Learning effectiveness was evaluated using a pre- and post-test design. Learning gains were analysed through descriptive comparison, with percentage improvement calculated to assess changes in learners' conceptual understanding, measurement accuracy, and CNC machining readiness following the VR-based learning intervention.

A pilot implementation was conducted with a group of machining students and instructors to assess the system's usability, learning effectiveness, and user experience. Feedback collected from participants was used to refine interface design, instructional clarity, and navigation flow, ensuring the innovation remains accessible, relevant, and scalable for broader adoption across TVET institutions.

### 4.1 Development Platform and Tools

The VR learning environment was developed using **Artsteps**, an online 3D immersive environment builder that enables the creation of virtual exhibition-style spaces accessible through both desktop and VR interfaces. Artsteps was selected for its accessibility, low technical barrier, and compatibility with multiple devices—including VR headsets, laptops, and mobile browsers—making it suitable for implementation within Malaysian TVET institutions with varying levels of technological infrastructure.

Within Artsteps, the development process involved creating a VR learning space that presents visual references to precision measurement tools and related instructional materials. The digital environment was organised to reflect the layout and context of machining-related equipment, allowing learners to become familiar with the appearance and functions of various measurement instruments. Key tools presented in the environment included vernier callipers, micrometers, height gauges, dial indicators, and surface plates.

Instructional materials were embedded within the environment using Artsteps' information panels, hyperlinks, and multimedia display features. These elements allow learning content—such as explanatory notes, tool descriptions, demonstration videos, and supporting diagrams—to be presented alongside the visual representations of the tools. This approach enables learners to explore the environment while accessing structured learning materials related to measurement concepts and tool usage.

Learners navigate the environment through a first-person perspective using keyboard and mouse controls or VR-compatible devices. This spatial exploration allows students to move within the VR learning space, observe tools from different viewpoints, and access contextual learning materials provided through interactive information points.

The pedagogical design of the Artsteps environment follows a progressive scaffolding approach, beginning with conceptual explanations of measurement principles, followed by guided observation of tool demonstrations, and concluding with self-directed review of learning materials within the VR learning environment.

Table 1: **Learning phases for measurement tool integration in the VR Machine Workshop**

| **Learning Phase** | **Description** | **Tool Integration** |
|---|---|---|
| Concept Introduction | Learners explore measurement principles and the basic structure of tools through visual explanations and descriptive learning panels within the VR environment. | Information panels, 3D visual references |
| Guided Observation | Learners observe demonstrations of measurement tool usage through embedded videos, diagrams, and instructional materials. | Video demonstrations, multimedia displays |
| Self-Assessment | Learners answer embedded questions and reflection prompts while exploring the VR learning environment to reinforce understanding of measurement concepts and tool identification. | Interactive hotspots, linked question prompts |

## 4.2 Workflow Design and Development Stages

The development of the VR Machine Workshop followed a structured instructional design workflow adapted from the widely recognised ADDIE framework—Analysis, Design, Development, Implementation, and Evaluation. This systematic process ensured that the innovation was pedagogically grounded and aligned with the practical learning needs of TVET students and instructors.

During the **Analysis phase**, consultations were conducted with machining instructors and students to identify common learning challenges related to measurement tools and machining practices. Classroom observations revealed several constraints in conventional workshop training, including limited access to precision instruments, safety considerations, and restricted opportunities for repeated conceptual explanation during practical sessions. Based on these findings, the learning objectives were aligned with the National Occupational Skills Standard (NOSS) for CNC Machining Level 3.

The **Design phase** focused on organising the structure of the VR learning environment and arranging the instructional materials in a logical learning sequence. The environment was designed to visually introduce measurement tools and their functions through explanatory panels, diagrams, and demonstration media. The goal of this phase was to create a clear learning flow that supports conceptual understanding before students engage with physical tools in workshop-based training.

In the **Development phase**, the VR learning environment was created using the Artsteps platform. Visual representations of measurement tools and related instructional materials were organised within the digital space using information panels, multimedia content, and linked learning resources. These components allow learners to explore the environment while accessing explanations, demonstrations, and guided learning prompts related to measurement concepts.

The **Implementation phase** involved introducing the VR learning environment to a group of **30 Sijil Kemahiran Malaysia (SKM) Level 3 CNC Machining students** over a four-week training period. Students explored the environment as a preparatory learning activity before participating in physical workshop sessions. Instructors facilitated the sessions by guiding learners through the instructional materials and encouraging self-directed exploration of the digital environment.

Finally, the **Evaluation phase** employed a mixed-method research design that combined quantitative and qualitative data collection to examine the effectiveness of the innovation. Quantitative data were obtained through pre- and post-tests that measured conceptual understanding, measurement accuracy, and tool identification skills. Complementary qualitative data were collected through interviews, reflective journals, and observation checklists to capture learners' engagement, perceptions, and overall learning experiences.

### 4.3 Data Collection and Analysis

To evaluate the effectiveness of the VR Machine Workshop, a pre- and post-test design was employed. The assessment involved **30 Sijil Kemahiran Malaysia (SKM) Level 3 CNC Machining students** who participated in the VR-based learning activities during the implementation phase.

The pre-test was administered prior to students' exposure to the VR learning environment in order to establish a baseline of their conceptual understanding of measurement tools and related machining principles. Following the learning sessions, a post-test was conducted to measure changes in students' understanding, tool identification skills, and measurement-related knowledge.

Quantitative data were analysed using **descriptive statistical comparison** between the pre-test and post-test results. Mean score differences and percentage improvements were calculated to determine the extent of learning gains following the VR-based learning intervention.

In addition to the quantitative assessment, qualitative data were collected through observation notes, learner reflections, and informal feedback discussions with instructors. These qualitative insights provided additional perspectives on learner engagement, perceived usefulness of the VR learning environment, and overall learning experiences.

Given that the study involved a relatively small sample drawn from a single training cohort, the results should be interpreted as **preliminary findings within a pilot implementation context**. Future studies may involve larger participant groups and longer implementation periods to further validate the effectiveness of VR-supported learning environments in TVET education.

### *4.3.1 Research Design*

The quantitative component measured improvements in learner performance through **pre- and post-tests** administered before and after the VR training module. The tests assessed three key aspects: **understanding of measurement theory**, **accuracy of tool readings**, and **ability to identify and handle precision instruments correctly**. Comparison of the pre- and post-test scores provided measurable evidence of learning improvement resulting from the VR-based training.

The qualitative component complemented these findings by exploring learners' experiences, perceptions, and engagement with the VR system. Data were collected through **semi-structured interviews, student reflection journals,** and **observation checklists** during the training sessions. The qualitative inquiry focused on dimensions such as motivation, usability, immersion, and perceived learning value of the virtual environment.

### *4.3.2 Sample and Procedure*

The study sample consisted of **30 Sijil Kemahiran Malaysia (SKM) Level 3 CNC Machining students** who participated in a four-week training programme. All participants completed the pre-test prior to engaging with the VR module and the post-test upon completion. During implementation, instructors served as facilitators and observers, recording patterns of engagement, common errors, and behavioural changes in learning. Interviews and reflections were collected immediately after the final session to capture fresh and authentic feedback from participants.

All procedures and data collection activities were conducted in accordance with institutional guidelines and administrative approval from ADTEC JTM Kampus Kuantan. Participant involvement was voluntary and anonymised for reporting purposes.

#### *4.3.3 Analysis Methods*

Quantitative data were analysed using descriptive statistical comparison between the pre- and post-test scores obtained from the **30 participating students**. Mean score differences and percentage improvement were calculated to determine the effectiveness of the VR Machine Workshop intervention in enhancing learners' conceptual understanding and measurement accuracy.

As the study involved a relatively small sample drawn from a single training cohort, the findings should be interpreted as preliminary evidence within the pilot implementation context.

Qualitative data were analysed using **thematic analysis** through an inductive approach. Interview transcripts, reflection journals, and observation notes were coded to identify recurring themes such as learning motivation, self-confidence, ease of use, and perceived usefulness of the embedded learning prompts and instructional materials. Triangulation of both quantitative and qualitative findings provided a holistic view of learner performance (objective outcomes) and user experience (subjective engagement).

#### *4.3.4 Reliability and Validity*

To ensure data reliability and validity, all research instruments—including test items, observation sheets, and interview protocols—were reviewed by three subject matter experts in machining and TVET pedagogy. The pre- and post-tests contained identical items presented in different sequences to minimise recall bias. Additionally, interviews were conducted by independent researchers not directly involved in instruction to avoid subjective influence.

#### *4.3.5 Preliminary Findings*

Quantitative analysis revealed an overall 27% improvement in post-test scores, indicating a substantial increase in learners' conceptual understanding and measurement proficiency. These findings are consistent with the quantitative results presented in Table 2. Qualitative feedback further supported these outcomes, with participants reporting that the VR-based training provided a more engaging, comprehensible, and safe learning experience compared to traditional workshop practice. Learners consistently identified the guided learning prompts and instructional materials as the most helpful features, as they supported clearer understanding of measurement concepts.

## 5 Findings and Discussions

The evaluation of the VR Machine Workshop produced substantial evidence of its educational, technical, and institutional impact within the Malaysian TVET context. The integration of both quantitative and qualitative data provided a holistic understanding of how immersive VR learning environments can enhance teaching effectiveness and learning experiences in machining-based training.

### 5.1 Quantitative Findings: Learning Gains and Performance Outcomes

Pre- and post-test analyses revealed notable improvements in learners' comprehension and measurement accuracy following the VR Machine Workshop intervention. Across the cohort of 30 trainees, post-test scores improved by an overall average of 27%, with the most prominent gains observed in reading precision, error detection, and appropriate tool identification

Table 2: **Pre- and Post-Test Learning Outcomes Following VR Machine Workshop Intervention**

| Assessment Area | Pre-Test Mean Score (%) | Post-Test Mean Score (%) | Improvement (%) |
|---|---|---|---|
| Measurement tool selection (steel rule, vernier calliper, micrometer) | 58 | 82 | +24 |
| Measurement accuracy and reading interpretation | 61 | 86 | +25 |
| Thread identification and pitch measurement | 55 | 83 | +28 |
| Alignment awareness using Dial Test Indicator (DTI) | 57 | 84 | +27 |
| CNC machining readiness (milling & lathe concepts) | 60 | 87 | +27 |
| **Overall mean learning gain** | **58** | **85** | **+27** |

As shown in Table 2, learners demonstrated faster recognition of measurement values and higher consistency in repeat measurements after VR-based practice. These findings suggest that immersive VR learning environments can help bridge the gap between conceptual understanding and practical workshop application.

By exploring visual representations of measurement tools prior to entering the physical workshop, learners developed clearer mental models that translated effectively into real-world performance. As one instructor noted, "When they finally entered the real workshop, I didn't have to repeat the basic demonstrations — they already knew how to hold and read the tools correctly."

The quantitative improvements also align with constructivist learning theory, which emphasises active engagement and reflection in knowledge construction (Billet 2001). The system's learning prompts and instructional explanations helped reinforce correct measurement interpretation, reinforcing procedural accuracy and fostering learner independence.

### 5.2 Qualitative Insights: Learner Engagement, Confidence, and Motivation

The qualitative data — derived from semi-structured interviews, reflection journals, and instructor observations — revealed deeper insights into learners' emotional and cognitive engagement. Thematic coding identified four recurring themes: motivation, confidence, autonomy, and feedback-driven learning.

Learners consistently expressed that the VR Machine Workshop made complex measurement concepts more approachable and less intimidating. Many described the virtual environment as "safe," "realistic," and "fun to use." One participant reflected,

"In the VR workshop, I can practice until I get it right. I don't have to worry about breaking anything or using up materials."

This sense of psychological safety was pivotal in building confidence among beginners, especially those who were hesitant to use real tools. Another trainee shared,

"It felt like being in the real lab, but I could stop, replay, and try again anytime. That helped me understand measurement much better before I touched the real tool."

The freedom to learn through trial and error encouraged intrinsic motivation, aligning with self-determination theory, where autonomy and competence are key to sustained engagement.

From the instructors' perspective, the change was equally evident. One instructor commented,

"Students came to the physical lab better prepared. I spent less time explaining the basics and more time refining their techniques."

This observation underscores how the innovation improved teaching efficiency and reshaped classroom dynamics, enabling instructors to shift from repetitive demonstration toward higher-level coaching and mentoring.

Overall, both learners and educators agreed that the VR workshop created a more interactive, less intimidating, and more efficient learning culture, turning what was once a procedural exercise into a dynamic and enjoyable experience.

### 5.3 Institutional and Pedagogical Impact

The innovation extended its benefits beyond the individual learner level to significantly influence institutional practice and pedagogical design. Instructors reported that the system streamlined their teaching workflows, reducing dependency on physical equipment for basic skill familiarization. This not only minimised scheduling conflicts but also optimized workshop utilization.

One department head noted during feedback discussion, "Previously, students had to queue for each tool. Now, they complete VR training first — so when they enter the real lab, they use time more efficiently."

Instructor observations and learner feedback also provided useful insights for improving lesson planning and instructional delivery. Instructors could monitor completion rates, identify common error trends, and adjust lesson plans accordingly. This marks a shift toward data-driven pedagogy, aligning with the global trend of integrating analytics into vocational education (UNESCO-UNEVOC 2022).

From an operational perspective, the system contributed to institutional sustainability by reducing material waste, equipment wear, and energy consumption. The digital format allowed asynchronous learning, giving students flexibility to practice outside formal class hours. These advantages align closely with Malaysia's TVET Digitalization Roadmap 2030, emphasising sustainability, inclusivity, and innovation in skill delivery.

### 5.4 Discussion: Educational Implications and Broader Significance

The findings demonstrate that the VR Machine Workshop contributes to bridging theoretical understanding and practical workshop learning through an immersive visual learning approach. The use of Virtual Reality (VR) as a digital learning medium supports improved conceptual understanding of measurement tools and machining principles while enhancing learner engagement. These findings are consistent with recent studies that highlight the educational potential of VR-based environments in vocational education contexts (Long et al. 2024; Thomann 2024).

The recorded increase of 27 percentage points in the overall score provides quantitative evidence that the VR learning environment can strengthen learners' conceptual understanding of measurement principles prior to hands-on workshop activities. By allowing learners to explore visual representations of measurement tools alongside explanatory materials and demonstrations, the system helps learners become more familiar with tool functions and measurement concepts before engaging with physical instruments in workshop settings. This outcome aligns with experiential learning theory, which emphasises active engagement, visualisation, and repeated exposure to learning materials as important mechanisms for effective skill development (Kolb 2015).

From a broader TVET perspective, the VR Machine Workshop addresses several long-standing constraints in workshop-based training by providing an accessible digital learning resource that complements physical instruction. The environment enables students to review learning materials, observe measurement tools, and reinforce conceptual knowledge before participating in practical workshop activities. These findings support recent literature that identifies immersive technologies as promising tools for enhancing instructional effectiveness and learner engagement in vocational education, particularly within digitally evolving training systems (Muskhir et al. 2024).

Although the study adopts an AI-ready conceptual framing, the reported findings primarily reflect the effectiveness of immersive VR learning supported by structured instructional materials and guided learning prompts rather than autonomous AI-driven processes. Nevertheless, the platform establishes a potential foundation for future integration of intelligent learning technologies in TVET environments, such as adaptive learning guidance and personalised learning support (Abu Bakar et al. 2024). The study therefore positions VR-based learning environments as a practical pathway for enhancing instructional quality and supporting workforce readiness in machining-related TVET education.

## 6 Conclusion and Future Work

This study demonstrates that the VR Machine Workshop provides a useful digital learning approach for supporting machining education within the TVET context. By presenting measurement tools and related instructional materials within a VR learning environment, the system helps learners develop clearer conceptual understanding before engaging with physical instruments in workshop sessions. The pre-test and post-test comparison showed an overall learning improvement of **27%**, indicating that the VR-based learning materials contributed positively to students' understanding of measurement concepts.

Although the project is conceptually positioned as an **AI-ready learning environment**, the current implementation primarily delivers structured instructional materials through the VR platform rather than relying on autonomous AI-driven processes. Nevertheless, the platform provides a foundation for potential future development, where intelligent learning features such as adaptive learning guidance or personalised learning support may be explored in subsequent studies.

From a broader perspective, the VR Machine Workshop illustrates how digital learning environments can complement conventional workshop-based training in TVET institutions. By providing accessible visual learning materials and opportunities for self-paced exploration, the system can support students in preparing for practical workshop activities while reducing reliance on limited physical resources.

However, several limitations should be acknowledged. The study was conducted as a pilot implementation involving a relatively small sample of **30 SKM Level 3 CNC Machining students** from a single training institution over a limited training period. As such, the findings should be interpreted as preliminary evidence of the effectiveness of the VR Machine Workshop within this specific training context. Future research may involve larger and more diverse participant groups, longer implementation periods, and cross-institutional evaluations to further examine the effectiveness and scalability of VR-supported learning in TVET education.

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## References

Abu Bakar, M. H., Md Ghafar, N. H., & Abdullah, F. (2024). Exploring the integration of artificial intelligence in technical and vocational education and training (TVET): applications, benefits, challenges, and future prospects. In: Politeknik Mukah Journal, 3(Special Issue), 57–63.

Billett, S. (2001). Learning in the Workplace: Strategies for Effective Practice. St Leonards: Allen & Unwin.

Editorial Issue 21 (2023). The role of excellence in TVET and emerging megatrends such as digitalisation and artificial intelligence. In*:* TVET@Asia, Issue 21.

Editorial Issue 24 (2025). Vocational didactics I: Construction technology, wood technology and color technology and interior design. In*:* TVET@Asia*,* Issue 24.

Irsyad, I. (2025). Economic benefits of technological innovation in education, with focus on AI in TVET. In: Oman Journal of Technology and Progress, 10, 1, 01–07.

Kolb, D. A. (2015). Experiential Learning: Experience as the Source of Learning and Development (2nd ed.). Upper Saddle River, NJ: Pearson Education.

Kuckartz, U. (2014). Qualitative Text Analysis: A Guide to Methods, Practice and Using Software. London: SAGE Publications.

Long, Y., Zhang, X., & Zeng, X. (2024). Application and effect analysis of virtual reality technology in vocational education practical training. In: Education and Information Technologies*,* 30, 9755–9786.

Ministry of Human Resources Malaysia. (2023). TVET Digitalization Roadmap 2030. Putrajaya: Department of Skills Development (DSD), Ministry of Human Resources Malaysia.

Muskhir, M., Luthfi, A., Watrianthos, R., Usmeldi & Samala, A. D. (2024). Emerging research on virtual reality applications in vocational education: A bibliometric analysis. In: Journal of Information Technology Education: Innovations in Practice, 23, 1-22.

Thomann, H. (2024). How effective is immersive virtual reality for vocational education? In: Computers & Education.

TVET@Asia (2025). Call for Papers: The Impact of Artificial Intelligence (AI) on Technical and Vocational Education and Training Systems and Teaching Practices. In: TVET@Asia, Issue 26.

UNESCO (2023). AI and Education: Guidance for Policy-Makers (2nd ed.). Paris: UNESCO Publishing. Online: https://doi.org/10.54675/PCSP7350 (retrieved 13.03.2026).

UNESCO-UNEVOC. (2022). Digitalization in TVET: The Global Context. Bonn: UNESCO-UNEVOC International Centre for Technical and Vocational Education and Training.

Weigel, T., Mulder, M., & Collins, K. (2007). The concept of competence in the development of vocational education and training in selected EU member states. In: Journal of Vocational Education & Training, 59, 1, 53–66. Online: https://doi.org/10.1080/13636820601145630 (retrieved 13.03.2026).

Zainuddin, Z., Shujahat, M., Haruna, H., & Chu, S. K. W. (2020). The role of gamified e-learning platforms in enhancing motivation and engagement: A systematic review. In: Computers & Education, 160, 104034. Online: https://doi.org/10.1016/j.compedu.2020.104034 (retrieved 13.03.2026).

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