International Journal of Research and Innovation Management
ISSN 2462-1293
Vol:11 No 1 2025

Exploring the Moderating Effect of Technological Self-Efficacy in Metaverse-Enhanced TVET Education

Darren Peter[1*], Azeyan Binti Awee[2], Peter Tan Sin Howe[3]
[1,2,3] Universiti Tunku Abdul Rahman, Kampar
*Corresponding author's email: darrenpeter018@gmail.com

Abstract : In the rapidly evolving educational landscape, Technical and Vocational Education and Training (TVET) emerges as a cornerstone for equipping learners with the practical skills required in the modern workforce. The advent of the Metaverse, an immersive digital ecosystem incorporating virtual and augmented reality, presents an unparalleled opportunity to revolutionize TVET by seamlessly integrating experiential learning with real-world applications. This study seeks to investigate the intricate dynamics within Metaverse-enhanced TVET education by focusing on the moderating role of technological self-efficacy. The research pursues three primary objectives: first, to explore the relationship between teacher development dimensions (comprising professional development, engagement with Metaverse tools, pedagogical training, and teachers' readiness) and teaching effectiveness in a Metaverse context. Second, it evaluates the moderating influence of technological self-efficacy on the nexus between teacher development dimensions and teaching effectiveness. Anchored in a quantitative research methodology, the study proposed a web-based survey for data collection and PLS-SEM for data analysis. The findings of this study are expected to significantly enrich the academic discourse on TVET education and Metaverse technologies, a domain that remains nascent globally and remarkably underexplored in Malaysia. Furthermore, the finding expected to bridge existing knowledge gaps, offering fresh insights into how digitalization and sustainable practices can redefine educational strategies in Malaysia's TVET sector.

Keywords: TVET Education, Metaverse, Teacher, Technological Self-Efficacy, Professional Development

1.0 INTRODUCTION

1.1 Background of the Study

Education is a fundamental driver of intellectual growth and socio-economic development, recognized as a human right by global conventions such as the Universal Declaration of Human Rights (UDHR) and the United Nations Sustainable Development Goals (SDGs) (Boeve-de Pauw & Halbac-Zamfir, 2020). Technical and vocational education and training (TVET) plays a critical role in education by equipping individuals with practical skills for employment, economic growth, and social mobility. TVET contributes to SDG#4 (Quality Education), SDG#8 (Decent Work and Economic Growth), and SDG#9 (Industry, Innovation, and Infrastructure), making it essential for workforce development. Globally, TVET is gaining recognition, with many countries, including Malaysia, implementing policies to enhance its impact. The Malaysian government has restructured its TVET system to align with industry demands, incorporating vocational training, digital transformation, and competency-based education to prepare graduates for a competitive job market. However, challenges remain, such as skills mismatches, educator competencies, and outdated curricula.

The COVID-19 pandemic exposed weaknesses in TVET, particularly in delivering hands-on training online. This accelerated the adoption of digital learning and new technologies to improve teaching effectiveness. Post-pandemic reforms have focused on enhancing digital tools, educator competencies, and standardized quality assurance systems. Technological advancements, including AI, AR, VR, and big data, transform TVET education by enhancing student engagement, personalized learning, and skill application in virtual environments. The Metaverse is emerging as a powerful tool for vocational training, allowing students to gain practical experience in simulated industrial, medical, and engineering environments without physical limitations. Despite its potential, the Metaverse faces challenges, such as high costs, infrastructure limitations, educator readiness, and digital accessibility.

Effective integration requires investment in professional development, policy adaptation, and collaboration between educators and industry experts.

Existing literature highlights the crucial role of teachers in the Metaverse, emphasizing the need for pedagogical training, digital competency, and engagement strategies. However, gaps remain in understanding teacher development and engagement in this evolving digital landscape. Future research should explore these dimensions to maximize the effectiveness of TVET in the digital era. TVET is vital for economic progress and skill development, particularly in emerging industries. With technological advancements reshaping vocational training, educators' readiness and digital integration will determine TVET's success in equipping students for the future workforce. Addressing the challenges in digital adoption and teacher development will be key to fully utilizing TVET's potential.

1.2 Problem Statement

Technological innovation has transformed multiple sectors, including education, with the Metaverse emerging as a virtual learning tool in TVET (Alhumaid, 2019; Hassan et al., 2024). While Onu et al. (2024) highlight the potential of the Metaverse in offering authentic occupational experiences without facility or location constraints, TVET teachers face significant challenges in achieving teaching effectiveness. A key issue is the digital literacy gap, as many instructors lack proper training in integrating virtual environments into their teaching (Reddy et al., 2023). Researchers had emphasized that these technologies demand advanced digital competencies, often exceeding educators' existing skills. Additionally, insufficient resources and infrastructure in many TVET institutions make it difficult for educators to optimize Metaverse-based learning (Hassan et al., 2024). This lack of digital proficiency further limits the pedagogical strategies available to improve the teaching experience.

Despite growing interest in integrating the Metaverse into TVET, there remains a significant research gap in understanding how educators can be systematically supported to enhance their digital proficiency and pedagogical effectiveness. While models like TPACK stress digital literacy, research seldom focuses on the unique demands of the Metaverse and the specific skills required for effective instruction. Additionally, technological self-efficacy is often overlooked despite its critical role in ensuring successful Metaverse adoption in TVET. Engagement is essential in bridging digital competence and teaching effectiveness in the Metaverse. Lindfors et al. (2021) argue that highly engaged educators are more likely to adopt and implement new technologies, leading to improved pedagogical practices. This study, therefore, considers technological self-efficacy as a moderator, assessing its influence on educators' ability to effectively use the Metaverse to enhance student outcomes. While existing studies provide preliminary insights into Metaverse-based teaching effectiveness, there is limited research on teacher development and engagement in this context. This study aims to address this gap by analyzing TVET teachers' behaviors and challenges in a specific geographic, economic, and political context, thereby enriching the literature on digital education strategies in TVET.

1.3 Research Objective and Question

RO1: To examine the teacher development dimensions that affect teaching effectiveness through the Metaverse.

RO2: To examine the moderating effect of technological self-efficacy between teacher development dimensions and teaching effectiveness through the Metaverse.

1.4 Underpinning Theories

Technological Pedagogical Content Knowledge (TPACK)

The Technological Pedagogical Content Knowledge (TPACK) Framework, introduced by Mishra and Koehler (2006), extends Shulman's (1986) Pedagogical Content Knowledge by integrating technological knowledge, recognizing the vital role of digital tools in education. Comprising three core knowledge domains; Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK) where TPACK also includes intersecting knowledge areas: Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), and Pedagogical Content Knowledge (PCK), which converge into a holistic TPACK understanding. This framework is particularly relevant in Metaverse-enhanced Technical and Vocational Education and Training (TVET), where immersive technology requires teachers to harmonize pedagogy, content, and technological tools effectively.

In Metaverse-based TVET, TPK is central for crafting engaging and purposeful learning experiences. Teachers with strong TPK can select and implement appropriate technological tools aligned with their pedagogical strategies. Orozco-Rodríguez et al. (2023) observed that such teachers foster highly interactive virtual classrooms. For example, an electrical engineering instructor may use VR to guide students through complex wiring systems, offering real-time feedback that enhances problem-solving and technical skills. TPACK also places value on Technological Content Knowledge (TCK) when it comes to managing curriculum delivery with the vision of TVET. TCK presupposes an understanding of how technology can help to extend content representation that is rather important in the TVET context, where processes and skills can be as well as are most frequently created and demonstrated visually. As Mishra and Koehler (2006) state, TCK is indispensable in technical education and necessary in VR and AR, as Tan et al. (2023) prove. For example, in culinary arts, an AR tool displaying instructions in a kitchen enables the teacher to look at the part by demonstrating precision and methods of handling food items. This more practical experience allows them to develop more precision and assurance skills, which are common in colleges like the hospitality industry. Professionals with high TCK can utilize immersive technologies to help explain complex vocational responsibilities with practical demonstrations, reducing the theory-practice gap.

Furthermore, based on the TPACK framework, the study responds to the call to investigate technological self-efficacy as a moderating variable of Metaverse-integrated TVET. Technological self-efficacy is a teacher's confidence level in applying technology in their teaching, which is generally supported by a strong TPACK framework. According to Nsibande (2022), TPACK enhances adaptability and confidence amongst teachers using technology in learning. Vancouver underscored that TPACK determines technological self-efficacy. In TVET, this has the implication of teachers credibly utilizing the Metaverse technologies in the development of well-realized learning environments. For instance, if a welding instructor knows how to conduct recourses in virtual reality, then the instructor can take learners through welding procedures, the correct methods and mechanisms, and where they are incorrect, they can point out and rectify them in real time. This makes the learning process more efficient and enhances students' technical accuracy, and supports TVET's goal of developing workforce readiness in graduates.

In this context, the TPACK framework increases the improvement of Metaverse-based education by supporting teachers' engagement and technological self- efficacy. Teachers who are trying to use the immersive tools, showcase for the students how they can use the tools in order to introduce collective work, problem solving and skill learning. Additionally, when the teachers are assured of the competency in using these tools, the fully optimise the Metaverse, to ensure the vocational trainings are in line with the current market. By adopting them, the TPACK framework explained technology and pedagogy integration and supported TVET's goals of providing relevant, professionally-focussed training. Such

International Journal of Research and Innovation Management
ISSN 2462-1293
Vol:11 No 1 2025
integration presents the Metaverse as an enabler of change, in terms of innovative, adaptive environments for learning, which would adequately address existing student needs.

Self-Determination Theory

Self-Determination Theory (SDT), developed by Deci and Ryan (1985), offers a comprehensive framework for understanding human motivation, particularly within educational settings. It emphasizes the fulfillment of three core psychological needs—autonomy, competence, and relatedness—which foster intrinsic motivation. When these needs are met, learners are more engaged and driven by internal satisfaction. In the context of Metaverse-enhanced Technical and Vocational Education and Training (TVET), SDT helps explain how technological self-efficacy moderates the link between these psychological needs and learning outcomes. In terms of autonomy, SDT implies that Metaverse-based TVET teachers should encourage autonomy-supportive instruction. By allowing students to make choices and take responsibility for their learning, teachers increase motivation. Chiu (2021) highlights that autonomy-supportive digital teaching enhances learner engagement. For example, in an automotive mechanics' course, allowing students to choose diagnostic tools in a virtual environment promotes industry-relevant problem-solving, aligning with TVET's mission to cultivate innovative, proactive learners.

Competence, another vital need, is fulfilled when students feel capable of meeting professional demands. This sense of self-efficacy is developed through structured instruction, feedback, and immersive simulations. Cheng and Tsai (2020) observed that teacher participation in immersive environments boosts students' perceived competence. For instance, real-time instructor feedback on welding angles and pressure in a VR-based welding class helps students develop accurate skills and prepares them for workforce expectations, an essential TVET objective. SDT also applies to technological self-efficacy because it is an aspect that determines teachers' technological competence to generate engagement levels and act in ways that would fulfill the students' psychological needs. Technological self-efficacy affects the extent to which teachers can execute new tools and strategies for increasing students' self-autonomy, competence, and relatedness. Al-khresheh and Alkursheh (2024) opine that technological self-efficacy moderates the effectiveness of digital teaching intervention, where immersed teachers are more likely to utilize the given technology. For example, when training students in virtual healthcare, a teacher who fully understands VR can take students through appendicitis treatment, CPR, or injections. This confidence not only demonstrates the technological competency inherent in the program but also helps the integrant students attain significant and innovative healthcare competencies that TVET envisions, inter alia, to provide highly skilled professional training for industries in transition.

Relatedness, the need for social connection, is also essential in Metaverse-enhanced TVET. Unlike traditional online platforms, the Metaverse offers shared spaces that foster presence and collaboration. In programs like hospitality management, teachers can organize simulations or role-playing activities (e.g., hotel management), which mimic real-world teamwork and foster a sense of belonging. This experience mirrors the interpersonal skills required in industry while enhancing student connectedness. In summary, SDT provides a strong theoretical foundation for understanding the influence of technological self-efficacy in Metaverse-based TVET. By addressing students' psychological needs, educators can create dynamic, motivating learning environments. These practices reinforce TVET's commitment to producing industry-ready graduates equipped with both technical expertise and adaptive, self-driven learning behaviors.

International Journal of Research and Innovation Management
ISSN 2462-1293
Vol:11 No 1 2025

2.0 LITERATURE REVIEWS

Professional Development

Professional development refers to the continuous learning process for educators aimed at enhancing their skills in line with emerging educational technologies and methodologies (Fernández-Batanero et al., 2022). Metaverse-based professional development introduces experiential learning, allowing teachers to actively engage in VR and AR environments, unlike traditional workshops (Alfaisal et al., 2024). It emphasizes interactivity and adaptability, fostering engagement and comprehension (Adami et al., 2023). Educators can globally collaborate in shared virtual spaces (Brand, 2020), and the flexible, capsule-based learning supports individual needs (Damaševičius & Sidekerskienė, 2024). However, barriers include technology accessibility and connectivity (Kazmi, 2023). Despite these, the immersive nature of Metaverse development significantly enriches 21st-century education (Khalil & Jumani, 2024; Cheng & Qin, 2021).

Metaverse Tools Engagement

Metaverse tools engagement denotes the interaction with VR, AR, and XR technologies to transform conventional educational methods (Onu et al., 2024). These tools enhance experiential and collaborative learning. For instance, VR helps biology students understand complex structures, while AR supports vocational training through safe simulations (Thompson et al., 2020; AlGerafi et al., 2023). VR-based settings and AI tutors offer tailored learning, boosting motivation and reducing anxiety (Rane et al., 2023; Adıgüzel et al., 2023). However, challenges such as cost, access, and lack of teacher expertise hinder widespread use (Yaqoob et al., 2023). Still, Metaverse tools significantly support collaboration, customization, and active learning.

Pedagogical Training

Pedagogical training involves preparing teachers to integrate pedagogical knowledge with VR and AR in immersive education (Mohan, 2019). The Metaverse fosters experiential, active learning over traditional passive methods (Heilporn et al., 2021). Training includes managing virtual classrooms and interacting with AI avatars, enhancing confidence and comprehension (Anderson & Putman, 2020). Collaboration is central, enabling teachers from diverse backgrounds to co-teach and co-develop pedagogical methods (Liu et al., 2020). Nonetheless, high costs, technical demands, and teacher resistance present barriers (Meccawy, 2022). Still, this training equips educators to meet learners' diverse needs in future-focused education.

Teacher Readiness

Teacher readiness refers to the preparedness and confidence of educators to integrate VR, AR, and XR into teaching practices (Lee & Hwang, 2023). It requires both technological proficiency and pedagogical adaptability. Proficient educators can create immersive lessons such as virtual expeditions or AR demonstrations (Pramanik, 2024). Flexibility is essential, enabling the adaptation of content to immersive platforms (Oulahyane et al., 2024). However, readiness is often hindered by time, funding, and lack of institutional support, even among digitally literate teachers (Rawat & Hagos, 2024). Therefore, professional development and sustained support are vital for effective Metaverse integration.

Technological Self-Efficacy

Metaverse education technology self-efficacy means the extent to which teachers have confidence in applying human technologies like VR, AR, and XR in lesson plans and instructional practices. In the Metaverse, which calls for a blend of content knowledge/and or competence and pedagogical content knowledge/technological pedagogical content knowledge, technological self-efficacy plays a critical role in establishing how effective teachers can be in implementing the use of technology in their practice. High HH tech self-efficacy empowers teachers to integrate innovative teaching practices. In contrast, a distant low self-efficacy will reduce competence in utilizing these technologies for instructional practice, undermining their pedagogy value (Kwon et al., 2019).

Teaching Effectiveness through Metaverse

Teaching effectiveness in Metaverse education refers to the ability to deliver impactful, immersive instruction using VR and AR (Chafiq et al., 2024). The "learning by doing" approach enriches engagement and retention, e.g., history students virtually exploring past civilizations (Makransky & Mayer, 2022). These platforms support real-time collaboration, enhancing teamwork and learning outcomes (Qureshi et al., 2023). However, technological challenges, resource availability, and teacher training needs affect successful implementation (Wu & Hao, 2024). Despite obstacles, the Metaverse offers transformative educational opportunities through immersive and collaborative experiences that redefine effective teaching.

Proposed conceptual Framewok

The variables described above have been used to form a diagrammatic view of the research framework (Figure 1) and presents the hypothesis to be tested. To predict engagement in teaching effectiveness through Metaverse, the focus is on; the dimension of the teacher development, which includes professional development, Metaverse tools engagement, pedagogical training and teachers' readiness and technological self-efficacy towards teaching effectiveness through Metaverse.

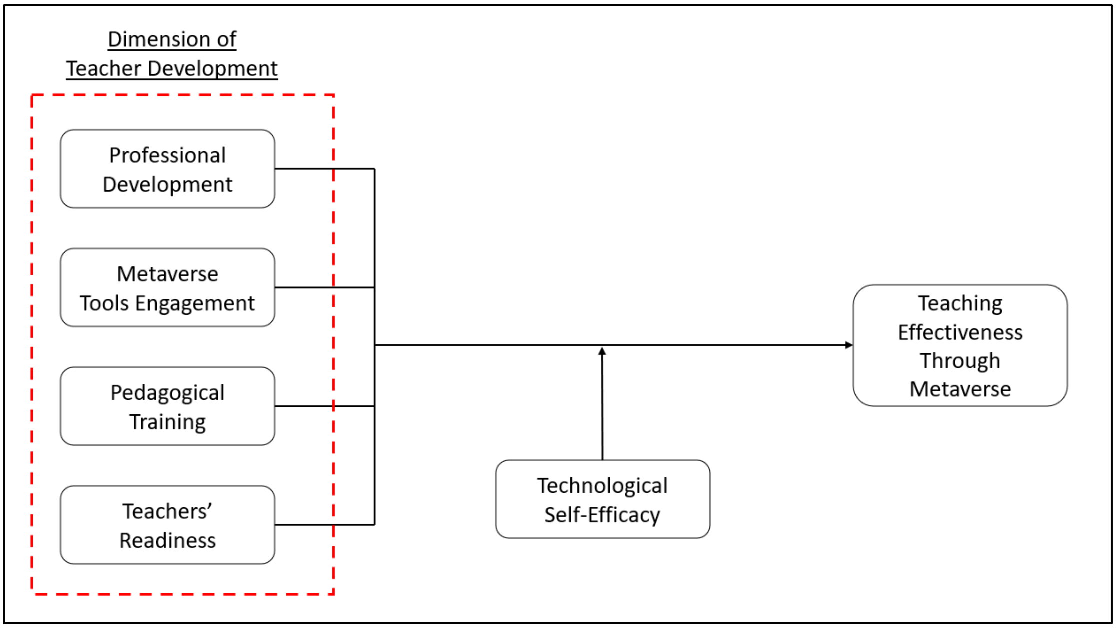

***Figure 1**: Conceptual Framework*

3.0 CONTRIBUTION OF THE STUDY

This conceptual paper contributes to the growing body of knowledge on digital transformation in education by proposing a theoretical model that highlights the moderating role of technological self-efficacy in Metaverse-enhanced TVET education. By integrating established theories, namely Self-Determination Theory (SDT) and the Technological Pedagogical Content Knowledge (TPACK) framework, the study provides a comprehensive understanding of how professional development, pedagogical training, teacher readiness, and engagement with Metaverse tools collectively influence teaching effectiveness. A key contribution of this study lies in its emphasis on technological self-efficacy as a central construct that bridges technological readiness and instructional outcomes. Moreover, the inclusion of technological self-efficacy as a moderating variable offers a nuanced perspective on how individual confidence in using technology can strengthen or weaken the proposed relationships. This conceptual framework not only advances theoretical discussions but also offers practical insights for policymakers, educational leaders, and curriculum developers seeking to implement immersive technologies in TVET settings. By outlining a future empirical validation plan, the study also sets the foundation for subsequent quantitative investigations, thereby encouraging evidence-based strategies to enhance teaching and learning experiences in the era of digital education.

4.0 CONCLUSION

In conclusion, this conceptual paper underscores the critical role of technological self-efficacy in enhancing the effectiveness of Metaverse-integrated Technical and Vocational Education and Training (TVET). By synthesizing insights from Self-Determination Theory (SDT) and the Technological Pedagogical Content Knowledge (TPACK) framework, the study elucidates how factors such as professional development, pedagogical training, teacher readiness, and interaction with Metaverse tools collectively influence teaching outcomes. The proposed conceptual model highlights technological self-efficacy as a pivotal moderator that bridges the gap between technological preparedness and instructional efficacy. Furthermore, the inclusion of technological self-efficacy as a moderating variable provides a nuanced understanding of individual confidence in technology use, which can either strengthen or attenuate the proposed relationships. This framework not only advances theoretical discourse but also offers practical implications for policymakers, educational leaders, and curriculum developers aiming to implement immersive technologies in TVET settings. By outlining a pathway for future empirical validation, the study lays the groundwork for evidence-based strategies to enhance teaching and learning experiences in the digital education era.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Tunku Abdul Rahman, Kampar Campus, Perak, Malaysia, grant number IPSR/RMC/UTARRF/2023-C2/A03 for funding this research.

REFERENCES

Adami, P., Singh, R., Borges Rodrigues, P., Becerik-Gerber, B., Soibelman, L., Copur-Gencturk, Y., & Lucas, G. (2023). Participants matter: Effectiveness of VR-based training on the knowledge, trust in the robot, and self-efficacy of construction workers and university students. Advanced Engineering Informatics, 55(101837), 101837. https://doi.org/10.1016/j.aei.2022.101837

Adıgüzel, T., Kaya, M. H., & Cansu, F. K. (2023). Revolutionizing education with AI: Exploring the transformative potential of ChatGPT. Contemporary Educational Technology.

Alfaisal, R., Hashim, H., & Azizan, U. H. (2024). Empowering the metaverse in education: ChatGPT's role in transforming learning experiences. In Communications in Computer and Information Science (pp. 13–31). Springer Nature Switzerland.

AlGerafi, M. A., Zhou, Y., Oubibi, M., & Wijaya, T. T. (2023). Unlocking the potential: A comprehensive evaluation of augmented reality and virtual reality in education. Electronics 2023, 12(18), 3953; https://doi.org/10.3390/electronics12183953

Alhumaid, K. (2019). Four ways technology has negatively changed education. Journal of Educational and Social Research, 9(4). https://doi.org/10.36941/jesr-2019-0002

Anderson, S. E., & Putman, R. S. (2020). Special education teachers' experience, confidence, beliefs, and knowledge about integrating technology. Journal of Special Education Technology: A Publication of Utah State University, the Association for Special Education Technology, and the Technology and Media Division of the Council for Exceptional Children, 35(1), 37–50. https://doi.org/10.1177/0162643419836409

Badilla-Quintana, M. G., & Sandoval-Henríquez, F. J. (2021). Students' immersive experience in initial teacher training in a virtual world to promote sustainable education: Interactivity, presence, and flow. Sustainability, 13(22), 12780.

Baig, A. I. (2023). Learning in the Metaverse: Challenges, Opportunities, and Threats (Doctoral dissertation, Department of Computing A thesis submitted in partial fulfillment of the requirements for the degree of Masters of Science in Innovative Technologies in Learning (MS ITL) In School of Electrical Engineering & Computer Science (SEECS), National University of Sciences and Technology).

Bakkar, I. B., & Ziden, A. A. (2023). Analysis of Perceptions and Insights of E-Learning Implementation in Educational Institutions by Educators, Students, and Parents. International Journal of Academic Research in Progressive Education and Development, 12(4).

Bandura, A. (1986). Social foundations of thought and action. Englewood Cliffs, NJ, 1986(23-28), 2.

Bandura, A. (1997). Self-efficacy: The exercise of control (Vol. 604). Freeman.

Brand, B. R. (2020). Integrating science and engineering practices: outcomes from a collaborative professional development. International Journal of STEM Education, 7(1). https://doi.org/10.1186/s40594-020-00210-x

Cavinato, A. G., Hunter, R. A., Ott, L. S., & Robinson, J. K. (2021). Promoting student interaction, engagement, and success in an online environment.

Chafiq, N., Cummins, P. W., Al-Qatawneh, K. S., & El Imadi, I. (Eds.). (2024). Navigating Virtual Worlds and the Metaverse for Enhanced E-Learning. IGI Global.

Cheng, K. H., & Tsai, C. C. (2020). Students' motivational beliefs and strategies, perceived immersion and attitudes towards science learning with immersive virtual reality: A partial least squares analysis. British Journal of Educational Technology, 51(6), 2140-2159.

Cheng, L., & Qin, J. (2021, December). Rethinking educational excellence with the digital transformation: a new perspective on developing tech-driven virtual mentoring platform for unfinished learning amid COVID-19. In 2021 IEEE International Conference on Engineering, Technology & Education (TALE) (pp. 1017-1022). IEEE.

Chiu, T. K. (2021). Digital support for student engagement in blended learning based on self-determination theory. Computers in Human Behavior, 124, 106909.

Damaševičius, R., & Sidekerskienė, T. (2024). Virtual worlds for learning in metaverse: a narrative review. Sustainability, 16(5), 2032.

Deci, E. L., & Ryan, R. M. (1985). The general causality orientations scale: Self-determination in personality. Journal of research in personality, 19(2), 109-134.

Fernández-Batanero, J. M., Montenegro-Rueda, M., Fernández-Cerero, J., & García-Martínez, I. (2022). Digital competences for teacher professional development. Systematic review. European Journal of Teacher Education, 45(4), 513–531. https://doi.org/10.1080/02619768.2020.1827389

Hassan, A., Dutta, P. K., Gupta, S., & Mattar, E. (2024). Human-Centered Approaches in Industry 5.0: Human-Machine Interaction, Virtual Reality Training, and Customer Sentiment Analysis: Human-Machine Interaction, Virtual Reality Training, and Customer Sentiment Analysis (S. & Singh, Ed.). IGI Global.

Heilporn, G., Lakhal, S., & Bélisle, M. (2021). An examination of teachers' strategies to foster student engagement in blended learning in higher education. International Journal of Educational Technology in Higher Education, 18(1), 25. https://doi.org/10.1186/s41239-021-00260-3

Kazmi, Z. S. (2023). Exploring the Digital Divide in Educational Technology across Illinois School Districts: a Focus on Business Education in Urban, Suburban, and Rural Schools.

Khalil, A., & Jumani, N. B. (2024). Feasibility of educational metaverse for immersive transformation of teacher education. Journal of Arts and Social Sciences, 11(1), 95–106. https://doi.org/10.46662/jass.v11i1.456

Lee, H., & Hwang, Y. (2023). Training with, about, for Metaverse: A Mixed Methods Research on Training Pre-Service Teachers as Metaverse-Certified Practitioners. Journal of English Teaching through Movies and Media, 24(4), 73–93.

Lindfors, M., Pettersson, F., & Olofsson, A. D. (2021). Conditions for professional digital competence: the teacher educators' view. Education Inquiry, 12(4), 390–409. https://doi.org/10.1080/20004508.2021.1890936

Liu, R., Wang, L., Lei, J., Wang, Q., & Ren, Y. (2020). Effects of an immersive virtual reality-based classroom on students' learning performance in science lessons. British Journal of Educational Technology: Journal of the Council for Educational Technology, 51(6), 2034–2049. https://doi.org/10.1111/bjet.13028

Makransky, G., & Mayer, R. E. (2022). Benefits of taking a virtual field trip in immersive virtual reality: Evidence for the immersion principle in multimedia learning. Educational Psychology Review, 34(3), 1771–1798. https://doi.org/10.1007/s10648-022-09675-4

Meccawy, M. (2022). Creating an immersive XR learning experience: A roadmap for educators. Electronics, 11(21), 3547.

Mishra, P., & Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A framework for teacher knowledge. Teachers College Record (1970), 108(6), 1017–1054. https://doi.org/10.1177/016146810610800610

Mohan, R. (2019). Innovative science teaching. PHI Learning Pvt. Ltd..

Onu, P., Pradhan, A., & Mbohwa, C. (2024). Potential to use metaverse for future teaching and learning. Education and Information Technologies, 29(7), 8893–8924. https://doi.org/10.1007/s10639-023-12167-9

Orozco-Rodríguez, C., Vera-Soria, G., & Vera-Soria, F. (2023). | Effect of PK, TK and TPK on the Efficacy of Teaching Practice in Covid-19 Times. IEEE Revista Iberoamericana de Tecnologias Del Aprendizaje.

Oulahyane, K., Youssfi, M., & Benmoussa, N. (2024). Embracing metaverse education: Transforming the landscape of learning. 2024 IEEE 12th International Symposium on Signal, Image, Video and Communications (ISIVC).

Pramanik, S. (2024). Immersive Innovations: Exploring the Use of Virtual and Augmented Reality in Educational Institutions. In Augmented Reality and the Future of Education Technology (pp. 66–85). IGI Global.

Qureshi, M. A., Khaskheli, A., Qureshi, J. A., Raza, S. A., & Yousufi, S. Q. (2023). Factors affecting students' learning performance through collaborative learning and engagement. Interactive Learning Environments, 31(4), 2371–2391. https://doi.org/10.1080/10494820.2021.1884886

Rane, N., Choudhary, S., & Rane, J. (2023). Education 4.0 and 5.0: Integrating artificial intelligence (AI) for personalized and adaptive learning. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4638365

Rawat, D. B., Alami, H. E., & Hagos, D. H. (2024). Metaverse survey & tutorial: Exploring key requirements, technologies, standards, applications, challenges, and perspectives. In arXiv [cs.HC]. http://arxiv.org/abs/2405.04718

Reddy, P., Chaudhary, K., & Hussein, S. (2023). A digital literacy model to narrow the digital literacy skills gap. Heliyon, 9(4).

Tan, L., Thomson, R., Koh, J. H. L., & Chik, A. (2023). Teaching multimodal literacies with digital technologies and augmented reality: A cluster analysis of Australian teachers' TPACK. Sustainability, 15(13), 10190. https://doi.org/10.3390/su151310190

Thompson, M., Wang, A., Bilgin, C., Anteneh, M., Roy, D., Tan, P., Eberhart, R., & Klopfer, E. (2020). Influence of virtual reality on high school students' conceptions of cells. Journal of Universal Computer Science: J. UCS, 26(8), 929–946. https://doi.org/10.3897/jucs.2020.050

Wu, T., & Hao, F. (2024). Edu-Metaverse: Concept, architecture, and applications. Interactive Learning Environments, 32, 4352–4379.

Yaqoob, I., Salah, K., Jayaraman, R., & Omar, M. (2023). Metaverse applications in smart cities: Enabling technologies, opportunities, challenges, and future directions. Internet of Things, 23(100884), 100884. https://doi.org/10.1016/j.iot.2023.100884

Yildirim, B., Sahin Topalcengiz, E., Arikan, G., & Timur, S. (2020). Using virtual reality in the classroom: Reflections of STEM teachers on the use of teaching and learning tools. Journal of Education in Science, Environment and Health. https://doi.org/10.21891/jeseh.711779