Conceptualization Of A Research Model For Teacher Development Dimension And Teaching Effectiveness Through Metaverse

Darren Peter[1a]*, Azeyan Binti Awee[2b], Peter Tan Sin Howe[3c], Peter Yacob[4d]

*aUniversiti Tunku Abdul Rahman, Jalan Universiti, 31900 Kampar, Perak; darrenpeter018@gmail.com
[b]Universiti Tunku Abdul Rahman, Jalan Universiti, 31900 Kampar, Perak; azeyan@utar.edu.my
[c]Universiti Tunku Abdul Rahman, Jalan Universiti, 31900 Kampar, Perak; shtan@utar.edu.my
[d]Independent Scholar

[a)]Corresponding author: darrenpeter018@gmail.com
[d)]peteryacob68@gmail.com

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Abstract
In response to the growing demand for immersive and innovative educational technologies, this study conceptualizes and empirically validates a research model linking teacher development dimensions to teaching effectiveness through the Metaverse within Technical and Vocational Education and Training (TVET) institutions. Drawing upon the Technological Pedagogical Content Knowledge (TPACK) framework, the model incorporates four key constructs: professional development, pedagogical training, Metaverse tools engagement, and teacher readiness. Using a purposive sampling approach, data were collected from 146 TVET teachers actively engaging with Metaverse tools and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results demonstrate that professional development, pedagogical training, and teacher readiness significantly influence teaching effectiveness, while engagement with Metaverse tools showed no significant impact. These findings highlight the critical role of teacher preparedness and continuous capacity-building in leveraging immersive technologies for vocational instruction. The study offers theoretical advancement in technology-integrated teacher development models and practical insights for policymakers and institutional leaders aiming to drive digital transformation in education. Limitations and directions for future research are also discussed.

Keywords: Technical and Vocational Education and Training, metaverse, teaching effectiveness, teacher development, TPACK.

INTRODUCTION

In recent years, the global education landscape has been rapidly transforming due to the emergence of immersive technologies, with the Metaverse poised to redefine how teaching and learning are conceptualized and delivered (1). Particularly within Technical and Vocational Education and Training (TVET), the demand for innovative, experiential, and competency-based approaches has heightened the need to explore new digital frontiers for professional development and pedagogical effectiveness. However, despite the growing interest in virtual environments, integrating Metaverse platforms into teacher development models remains underexplored(2). This poses a significant challenge, as TVET teachers must continuously adapt to evolving technological demands while ensuring the effectiveness of their instructional practices. The problem lies in the absence of a structured and theory-driven framework that links Metaverse-based experiences to teacher development dimensions (professional development, pedagogical training, metaverse tools engagement, and teachers' readiness) and how these influences overall teaching effectiveness in Metaverse settings. Existing literature tends to focus either on general digital transformation in education or student engagement within immersive environments, neglecting the unique professional development needs and teaching challenges faced by TVET teachers(3). Moreover, empirical studies addressing how Metaverse technologies can support continuous teacher learning, improve instructional quality, and enhance TVET training outcomes are scarce[4]. These gaps signal an urgent need to conceptualize a model that contextualizes teacher development in immersive environments and establishes its correlation with teaching effectiveness.

The novelty of this study lies in its pioneering approach to conceptualizing a research model that bridges Metaverse technology and teacher development in the TVET context. Unlike previous works that treat digital transformation as a generic trend, this study positions the Metaverse as a transformative medium for professional learning, pedagogical enhancement, and instructional innovation. Focusing on TVET teachers who operate at the intersection of practical skills training and educational technology, this study offers a contextually grounded and forward-thinking model that addresses current educational disruptions and the pressing need for future-ready teaching competencies. It contributes to the academic discourse by laying the foundation for empirical validation and practical strategies to harness the Metaverse for sustainable teacher development and improved teaching effectiveness. Therefore, to address the gap of the study, this study is guided by 4 research questions:

RQ1: Is professional development related to teaching effectiveness through Metaverse?
RQ2: Is pedagogical training related to teaching effectiveness through Metaverse?
RQ3: Is metaverse tools engagement related to teaching effectiveness through Metaverse?
RQ4: Is teachers' readiness related to teaching effectiveness through Metaverse?

LITERATURE REVIEW

Integrating emerging technologies into teaching practices has brought renewed attention to teacher development frameworks emphasizing the interplay between technology, pedagogy, and content knowledge. One of the most widely recognized frameworks in this domain is the Technological Pedagogical Content Knowledge (TPACK) model, which highlights the complex relationship between a teacher's understanding of subject matter (Content Knowledge), teaching strategies (Pedagogical Knowledge), and technology use (Technological Knowledge)[5]. Within TVET education, where hands-on skills and technical instruction are pivotal, the TPACK framework provides a valuable lens for examining how digital and immersive tools like the Metaverse can enhance instructional quality and learner outcomes. A growing body of research supports the argument that teachers with well-integrated TPACK competencies are more likely to design and deliver practical, student- centered learning experiences using digital technologies[6,7]. This is particularly relevant for TVET teachers who must balance technical instruction with evolving industry practices. Researchers argue that Metaverse platforms can reinforce all three TPACK domains simultaneously by enabling immersive simulations, collaborative virtual environments, and real-time feedback as well as promoting deeper conceptual understanding and improved teaching effectiveness[8]. However, a counter-argument arises from critics who caution that adopting advanced technologies like the Metaverse may inadvertently marginalize teachers who lack the requisite digital fluency or institutional support[9]. Furthermore, some scholars argue that the TPACK model, while useful, may not fully capture the socio-technical complexities and infrastructure challenges inherent in implementing Metaverse tools in real-world classroom settings, particularly in under-resourced TVET institutions[10]. These critiques underscore the importance of context-specific research that considers both the opportunities and limitations of immersive technologies in teacher development.

Despite these debates, there remains a significant research gap in empirically validating the role of Metaverse platforms in shaping teacher competencies and teaching effectiveness within TVET[3]. Most existing studies center on higher education settings, with limited focus on TVET teachers who face unique pedagogical and technical demands[11]. This study addresses this critical gap by proposing a conceptual model grounded in the TPACK framework to explore how Metaverse-based interventions contribute to teacher development dimensions such as technological integration, pedagogical adaptability, and content delivery and

their subsequent impact on teaching effectiveness. The originality of this study lies in its pioneering integration of the TPACK model with Metaverse-enabled environments to conceptualize teacher development in a TVET context. Moving beyond conventional digital tools and emphasizing immersive, experiential platforms, this research introduces a novel perspective on how TVET teachers can be empowered to thrive in technology- mediated learning ecosystems. Unlike general educational technology studies, this work is uniquely positioned to influence both theoretical development and practical interventions tailored to the vocational education sector. Based on the above discussion, a diagrammatic view of the research framework (Figure 1) is presented, which presents the hypothesis to be tested.

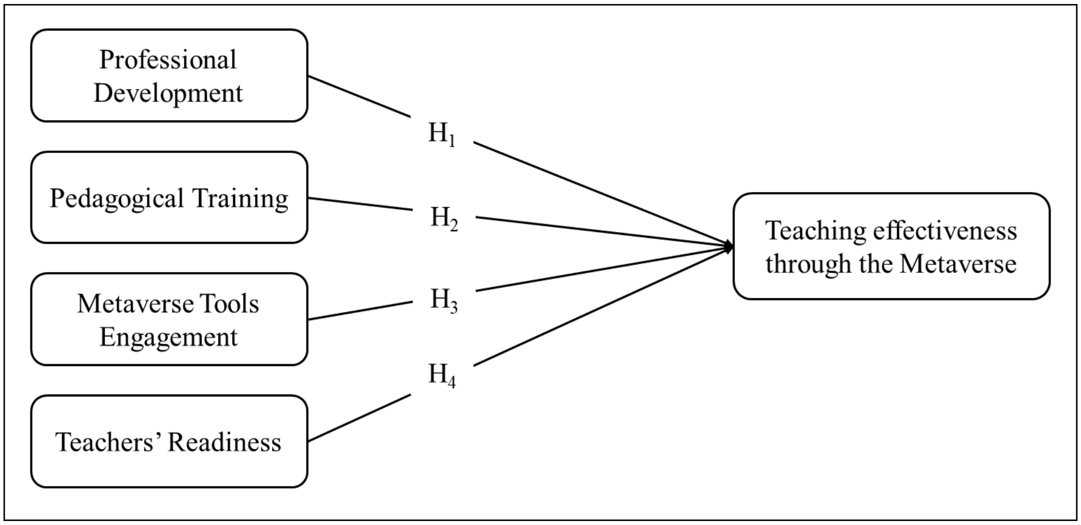

Fig. 1 Research Framework

H_1: There is a significant relationship between professional development and teaching effectiveness through the Metaverse

H_2: There is a significant relationship between linking pedagogical training and teaching effectiveness through the Metaverse

H_3: There is a significant relationship between Metaverse Tools Engagement and teaching effectiveness through the Metaverse

H_4: There is a significant relationship between teachers' readiness and teaching effectiveness through the Metaverse

METHODOLOGY

Due to its significance to education, the TVET teachers were chosen as the unit of measurement. As a result, this research engages TVET teachers, and the G*Power was used to identify the study's target population. Given the size of the target population and its dispersed locations around the country, the purposive sampling technique was chosen. The adoption of purposive sampling is rationalized by requiring specialized and context-specific insights. Using purposive sampling, the researchers carefully select TVET teachers who are recognized for their involvement in or current engagement with the Metaverse. This assures that the sample comprises respondents with pertinent experiences and insights that align with the study's objectives. The survey questionnaire was distributed online, and the link to the survey questionnaire was explicitly shared via Google Drive. A total of 146 TVET teachers were received. This complete participation strengthens the reliability and validity of the dataset, eliminating concerns related to non-response bias. To ensure data integrity, each response was screened for completeness, and all submissions were found to be suitable for analysis with no cases requiring elimination due to missing data. The high response rate may be attributed to the relevance of the research topic, effective engagement strategies, and the increasing interest among teachers in the potential of Metaverse technology to enhance teaching practices and professional development

Before proceeding with the primary data collection, the questionnaire underwent a pre-testing phase with two experts from TVET institutions. These two experts are ready to verify the questions' requirements and the consistency of easily understandable measures, which results in optimism regarding the respondents' answers. Initial evaluations of the scale questions minimize discrepancies between the survey and the assessed measures. The questions were revised after the pre-test to ensure validity and the respondents' comprehension of the questionnaire's criteria. Following a researcher suggestion, 30 TVET teachers piloted the questionnaire for this study. Five variables were considered when determining the internal accuracy of a measuring instrument using Cronbach's alpha coefficient[12].

All five of the study's variables have Cronbach's alpha values greater than the 0.7 cut-off point. The actual phase of data collection did not include the piloting respondents. To ensure the construct's validity and reliability, all constructs and assessment items were generated from previous research to fit into the context of this study. The items were rated on a five-point Likert scale ranging from 'strongly disagree' to 'strongly agree.' There are six sections to the questionnaire. Apart from the eleven demographic questions in Section A (Table 1), the study's five variables were measured using 30 items. Section B included six questions adapted from Darling-Hammond et al. (2017) to measure 'professional development'. Section C had six questions, which were also adapted from Darling-Hammond et al. (2017) to assess 'pedagogical training.' Section D used six questions adapted from Kye et al. (2021) to measure 'metaverse tools engagement.' Five questions derived from Clarke and Hollingsworth (2002) were used to assess 'teachers' readiness' in Section E. Finally, the dependent variable 'teaching effectiveness through metaverse' was evaluated in Section F using six questions adapted from Mystakidis (2022).

FINDINGS

This study used the PLS-SEM technique and the Smart PLS 4.0 program to test its research model. Both the outer (measurement) model and the inner (structural) model of the PLS route model are defined by systems of linear equations. According to a researcher, one model provides the connections between a concept and its measurable indicators, while another describes the connections between different concepts(13). Consequently, the study used PLS-SEM assessment and structural modeling to validate the hypotheses and achieve the research aim.

DEMOGRAPHIC ANALYSIS

Table 1 shows the respondents' demographic details regarding the TVET teachers' views on teaching effectiveness through the Metaverse.

TABLE 1. RESPONDENTS' DEMOGRAPHIC

	Frequency	%	Cumulative %
Gender			
Male	84	57.50%	57.50%
Female	62	42.50%	100.00%
Age Group			
Below 25 years	8	5.50%	5.50%
26 to 35 years	39	26.70%	32.20%
36 to 45 years	52	35.60%	67.80%
46 to 60 years	47	32.20%	100.00%
Location (State)			
Selangor	25	17.12%	17.12%
Johor	17	11.64%	28.76%
Sarawak	13	8.90%	37.67%
Sabah	13	8.90%	46.58%
Kedah	11	7.53%	54.11%
Perak	10	6.85%	60.96%
Negeri Sembilan	10	6.85%	67.81%
Penang	10	6.85%	74.66%
Melaka	8	5.48%	80.14%

Pahang	8	5.48%	85.62%
Kelantan	6	4.11%	89.73%
Terengganu	6	4.11%	93.84%
Putrajaya	4	2.74%	96.58%
Wilayah Persekutuan	3	2.05%	98.63%
Perlis	2	1.37%	100.00%
Education Level			
Degree	67	45.90%	45.90%
Master	46	31.50%	77.40%
PhD	17	11.60%	89.00%
High School	8	5.50%	94.50%
Other	8	5.50%	100.00%
Years of Teaching Experience in TVET			
Less than 1 year	4	2.70%	2.70%
1–3 years	19	13.00%	15.80%
4–6 years	32	21.90%	37.70%
7–10 years	38	26.00%	63.70%
More than 10 years	53	36.30%	100.00%
Primary Area of Teaching			
Engineering & Technology	52	35.60%	35.60%
ICT	29	19.90%	55.50%
Business & Management	21	14.40%	69.90%
Hospitality & Tourism	13	8.90%	78.80%
Health & Medical Sciences	11	7.50%	86.30%
Art & Design	10	6.80%	93.10%
Other	10	6.80%	100.00%
Technology Usage in Teaching			
Never	2	1.40%	1.40%
Rarely	9	6.20%	7.50%
Occasionally	27	18.50%	26.00%
Frequently	49	33.60%	59.60%
Always	59	40.40%	100.00%
Training in Metaverse Tools			
Extensive training	12	8.20%	8.20%
Some training	36	24.70%	32.90%
Self-learned through practice/research	49	33.60%	66.40%
No training	49	33.60%	100.00%
Technological Self-Efficacy Level			
Very low	5	3.42%	3.42%
Low	13	8.90%	12.33%
Moderate	43	29.45%	41.78%

High	65	44.52%	86.30%
Very high	20	13.70%	100.00%
Familiarity with the Metaverse			
Not familiar at all	8	5.48%	5.48%
Slightly familiar	23	15.75%	21.23%
Somewhat familiar	52	35.62%	56.85%
Very familiar	53	36.30%	93.15%
Expert-level	10	6.85%	100.00%
Primary Teaching Method(s)			
Lecture-based teaching	26	17.80%	17.80%
Hands-on practical training	43	29.50%	47.30%
Problem-based learning	18	12.30%	59.60%
Project-based learning	21	14.40%	74.00%
Online/virtual learning	14	9.60%	83.60%
Blended learning	21	14.40%	98.00%
Other	3	2.10%	100.00%

DESCRIPTIVE ANALYSIS

Table 2 illustrates the descriptive statistics with the mean score and the standard deviation of all study items. All of the items were found to be moderately related to the study's constructs and to have a normal distribution, indicating that they are all significant to the investigation and suitable for further analysis.

TABLE 2. DESCRIPTIVE STATISTICS

Factors	Code	Item	Mean	SD
Professional Development	PD1	I attend training/workshops related to Metaverse technologies.	4.18	0.71
	PD2	I seek opportunities to learn about Metaverse integration in TVET.	4.12	0.76
	PD3	I feel supported by my institution in my professional growth.	4.05	0.82
	PD4	I participate in continuous professional development programs.	4.2	0.74
	PD5	I collaborate with colleagues to enhance Metaverse-based teaching.	4.16	0.69
	PD6	I reflect on my practices to improve teaching using the Metaverse.	4.1	0.77
Metaverse Tools Engagement	MTE1	I actively use Metaverse tools in teaching.	4.25	0.68
	MTE2	I encourage students to use Metaverse tools in learning.	4.3	0.72
	MTE3	I explore various Metaverse applications for teaching.	4.21	0.7
	MTE4	I feel motivated to integrate Metaverse tools in lessons.	4.28	0.66
	MTE5	I engage in communities discussing Metaverse teaching tools.	4.19	0.73

	MTE6	I spend time experimenting with new Metaverse tools.	4.22	0.71
Pedagogical Training	PT1	I have received training on how to teach using the Metaverse.	4.15	0.75
	PT2	My pedagogical training includes digital teaching strategies.	4.08	0.79
	PT3	I am trained to adapt teaching methods for virtual environments.	4.18	0.7
	PT4	I understand how to manage a Metaverse-based classroom.	4.2	0.68
	PT5	I can assess student learning in the Metaverse context.	4.14	0.72
	PT6	I know how to structure effective lessons using Metaverse.	4.1	0.76
Teachers' Readiness	TR1	I am confident in using Metaverse for teaching.	4.23	0.69
	TR2	I am ready to integrate Metaverse into my teaching practices.	4.19	0.72
	TR3	I am prepared to face challenges in Metaverse-based teaching.	4.27	0.66
	TR4	I am technologically ready to conduct classes in the Metaverse.	4.24	0.7
	TR5	I have the necessary digital skills for Metaverse teaching.	4.26	0.68
	TR6	I am mentally ready to shift towards Metaverse-enhanced education.	4.18	0.74
Teaching Effectiveness Through Metaverse	TEM1	My teaching has improved since using Metaverse tools.	4.31	0.65
	TEM2	Students show better engagement when I use the Metaverse.	4.29	0.67
	TEM3	I deliver content more effectively using Metaverse platforms.	4.25	0.7
	TEM4	My students achieve better learning outcomes with Metaverse.	4.28	0.66
	TEM5	I can adapt Metaverse tools to meet students' learning needs.	4.26	0.68
	TEM6	My overall teaching effectiveness has increased with Metaverse.	4.32	0.64

ASSESSMENT OF THE MEASUREMENT MODEL

To ensure accuracy, the study used appropriate measuring items for all variables, and a rigorous validation under the measurement model (see Table 3) was conducted utilizing convergent and discriminant validity to assess construct validity. The study adhered to the guidelines proposed by a researcher as a criterion for validating convergent validity(14). The average variance extracted (AVE) was used to evaluate convergent validity. All of the constructs must be greater than 0.5 for AVE to be deemed well-established, and the same criterion must also be applied to the assessment of reflected measurement models(16). In addition to the average variance retrieved, factor loadings of items and composite reliability (CR) are utilized to assess the convergent validity of the data, with factor loadings referred to as outer loadings of the measurement model, which should exceed 0.70. Composite reliability is employed to evaluate measurement consistency, adhering to the guideline established by researcher Hair stipulating that composite reliability must exceed 0.70(15). The analysis demonstrates that all items had a loading exceeding 0.6(15). Consequently, no items were omitted from the latent variable. The CR ratings for each latent variable ranged from 0.947 to 0.897. The AVE values for all five components ranged from 0.743 to 0.661. The composite and AVE values are above the suggested level set(15). The developed measurement model has adequate convergent validity and reliability, signifying that the chosen indicators accurately represent the latent variable. Thereafter, discriminant validity was evaluated. Evaluating discriminant validity is crucial for affirming the measured construct, ensuring its empirical distinctiveness, and verifying that each construct accurately reflects the phenomena of interest that other measures fail to capture within the study model(16). This research assesses discriminant validity through a Heterotrait- Monotrait Ratio (HTMT) analysis introduced by Henseler for evaluating discriminant validity stipulates that the ratio value must not exceed 0.9 (Table 4) (17). This unequivocally demonstrates that all latent variables analyzed in this study are distinct from each other and fulfill the requirements for discriminant validity.

Table 3. Result of the measurement model

Variable	Item Code	Loading	AVE	CR
Professional Development (PD)	PD1	0.82	0.675	0.928
	PD2	0.834		
	PD3	0.825		
	PD4	0.832		
	PD5	0.82		
	PD6	0.767		
Metaverse Tools Engagement (MTE)	MTE1	0.801	0.665	0.93
	MTE2	0.775		
	MTE3	0.814		
	MTE4	0.808		
	MTE5	0.805		
	MTE6	0.817		
Pedagogical Training (PT)	PT1	0.8	0.672	0.915
	PT2	0.786		
	PT3	0.84		
	PT4	0.827		
	PT5	0.804		
	PT6	0.779		
Teachers' Readiness (TR)	TR1	0.846	0.72	0.938
	TR2	0.869		
	TR3	0.858		
	TR4	0.852		
	TR5	0.859		
	TR6	0.841		
Teaching Effectiveness Through Metaverse (TETM)	TEM1	0.794	0.679	0.948
	TEM2	0.757		
	TEM3	0.799		
	TEM4	0.77		
	TEM5	0.827		
	TEM6	0.861		

Notes: CR composite reliability; AVE average variance extract

Table 4. Heterotrait-Monotrait Ratio (HTMT Ratio)

Constructs	PD	MTE	PT	TR	TETM
Professional Development (PD)					
Metaverse Tools Engagement (MTE)	0.726				
Pedagogical Training (PT)	0.682	0.703			
Teachers' Readiness (TR)	0.588	0.675	0.64		
Teaching Effectiveness Through Metaverse (TETM)	0.705	0.778	0.667	0.754	

ASSESSMENT OF THE STRUCTURAL MODEL

The study involved evaluating the structural model to evaluate the suggested hypotheses and ascertain the link between the latent variables. The R2 indicates the model's prediction accuracy and signifies the quality of the model. The acceptable range of R2 and its corresponding suitable levels, according to the guideline established by Hair, categorizes R2 values of 0.75 as considerable, 0.50 as moderate, and 0.25 as weak[(15)]. The path coefficient elucidates the direction of the hypotheses established in the study and their correlation to the overarching construct selected for the study. The structural model comprises four independent variables: professional growth, pedagogical training, interaction with metaverse tools, and teachers' readiness. Figure 2 presents the findings of the direct effects of PLS-SEM analysis on professional growth, pedagogical training, involvement with metaverse tools, and teachers' readiness. The R2 value for teaching effectiveness via the metaverse (dependent variable) is 0.345, indicating that 34.5% of the variance in education can be attributed to professional development, Metaverse tools engagement, and teachers' readiness (exogenous variables). According to Hair, the model result for R2 in this study indicates a moderate level[(16)].

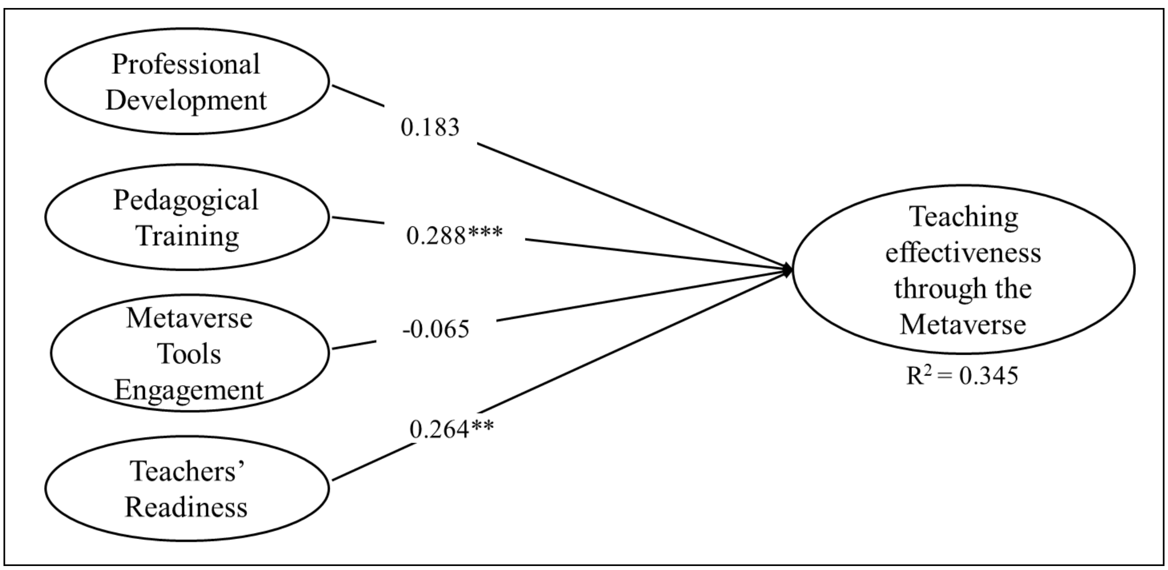

Figure 2: Measurement Model

Furthermore, the study proceeds to evaluate the structural model for hypothesis testing. As shown in Figure 2 and Table 4, three hypotheses were supported out of the four. Professional development on teaching effectiveness through metaverse ($\beta = 0.183$, $p < 0.05$); pedagogical training on teaching effectiveness through metaverse ($\beta = 0.288$, $p < 0.01$); teachers' readiness on teaching effectiveness through metaverse ($\beta = 0.264$, $p < 0.05$) were found to be significant. Consequently, hypotheses H_1, H_2, and H_4 are supported, whereas H_3, is not supported (see Table 5).

Table 5: Path Coefficient and Hypothesis Testing

Hypothesis	Relationships	Std. Beta	SE	t-value	Decision
H_1	Professional Development → Teaching Effectiveness Through Metaverse	0.183	0.087	2.094*	Supported
H_2	Pedagogical Training → Teaching Effectiveness Through Metaverse	0.288	0.076	3.760**	Supported
H_3	Metaverse Tools Engagement → Teaching Effectiveness Through Metaverse	-0.065	0.091	-0.717	Not Supported
H_4	Teachers' Readiness → Teaching Effectiveness Through Metaverse	0.264	0.083	3.172**	Supported

Note: * Significance at $p < 0.05$, **$p < 0.01$; bootstrapping (n = 1000). Beta = regression weight; t values are computed through a bootstrapping procedure

Alongside R2, the Q2 value, predictive relevance, was established to evaluate model fit. Predictive relevance (Q2) indicates the model's predictive capability. It assesses whether it effectively forecasts the proposed link, even after items were removed from the latent variables during the validation and reliability assessment[15]. The current investigation yielded a Q2 score of 0.268 for teaching effectiveness through the Metaverse, and the value exceeds zero and demonstrates measurement adequacy for the study model.

DISCUSSION

The findings of this study affirm the significant influence of Metaverse integration on enhancing teaching effectiveness in the context of TVET. Three teacher development dimensions examined (professional development, pedagogical training, and teacher readiness) demonstrated positive and significant relationships with teaching effectiveness, except for Metaverse tools engagement, which shows a negative relationship. These results offer robust empirical support to the research framework proposed in the study and provide critical insights into how immersive technologies can transform teacher development in TVET settings[18, 19]. The strong relationship identified between professional development and teaching effectiveness suggests that when TVET teachers engage in structured, immersive training opportunities, their instructional practices improve meaningfully. This aligns with contemporary research on immersive professional learning environments, highlighting the importance of hands-on and simulation-based training for advancing teaching practices[20,3]. The Metaverse, through its simulation-based and interactive environments, offers a dynamic platform where teachers can rehearse, reflect, and refine their instructional strategies in a risk-free setting, thereby enhancing their pedagogical competence and confidence.

Equally compelling is the demonstrated link between pedagogical training and teaching effectiveness. This reinforces the premise that pedagogical adaptability is crucial for effectively navigating the virtual and augmented learning environments enabled by the Metaverse. As TVET education necessitates not just content delivery but the cultivation of technical competencies, the immersive nature of Metaverse tools allows for more nuanced and realistic demonstrations of TVET skills. Recent studies confirm that immersive environments significantly enhance pedagogical practices and learner engagement when effectively aligned with teaching objectives[21, 22]. Despite this, the engagement with Metaverse tools emerged as a pivotal factor influencing teaching effectiveness, validating previous arguments favoring technological immersion as a catalyst for innovation in education[23]. This finding affirms the TPACK framework's assertion that technological fluency fosters more impactful teaching when integrated with pedagogical and content knowledge. Researchers stated that the Metaverse tools, including virtual labs, 3D modeling, and interactive avatars, can elevate both the instructional process and student engagement, but their efficacy hinges on the teachers' comfort and proficiency in using them[24, 25].

Furthermore, the positive correlation between teachers' readiness and teaching effectiveness underscores the significance of attitudinal and cognitive preparedness in driving successful technology adoption. Readiness reflects digital literacy and encompasses openness to innovation, adaptability to new pedagogical paradigms, and a growth mindset, essential for teachers operating in the Fourth Industrial Revolution (4IR) context[26]. This is particularly vital in TVET, where rapid technological evolution demands agile and proactive responses from teachers. The discussion confirms the proposed research model's validity and contributes to the emerging literature on Metaverse integration in education. Unlike general studies focusing on digital transformation, this study uniquely contextualizes the Metaverse within the TVET framework, filling a notable gap. It advances theoretical discourse by applying the TPACK framework to immersive environments and demonstrates the practical implications of equipping teachers with the requisite tools, skills, and mindsets to thrive in digitally augmented learning spaces. Importantly, the findings signal the need for institutional investment in Metaverse-based teacher training programs, capacity-building initiatives, and supportive infrastructure to sustain long-term pedagogical innovation in TVET education[27].

IMPLICATIONS OF THE STUDY

Apart from the findings and discussion, this study has theoretical and policymaker implications.

THEORETICAL IMPLICATIONS

This study contributes significantly to the growing theoretical discourse on technology-enhanced teacher development, particularly within immersive technologies. By integrating the TPACK framework into a Metaverse-based TVET environment, this study expands the theoretical boundaries of the TPACK model and immersive learning paradigms. It demonstrates that teaching effectiveness can be systematically linked to multidimensional teacher development dimensions (professional development, pedagogical training, tool engagement, and readiness) in an immersive virtual environment. Moreover, the study addresses a notable gap in educational technology research by contextualizing these variables within TVET, a domain often underrepresented in digital transformation literature. It also reinforces the evolving understanding of teacher readiness as a cognitive and affective construct influencing innovation adoption in complex, technology-rich settings.

POLICYMAKER IMPLICATIONS

From a policy perspective, this research provides crucial insights for educational authorities, curriculum designers, and institutional leaders responsible for enhancing teacher capacity in TVET institutions. The findings suggest that strategic investments in immersive professional development programs and institutional support for teacher readiness and technological infrastructure are essential for the successful implementation of Metaverse-based teaching. Policymakers should consider formulating national or regional frameworks incorporating Metaverse technologies into teacher training standards. Furthermore, guidelines and funding should be available to support Metaverse integration as a supplementary tool and a core component of digital pedagogy, especially in vocational training programs that benefit from experiential and hands-on simulations.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

While the study offers valuable insights, it is not without limitations. First, the sample size, although adequate for PLS-SEM, was limited to 146 TVET teachers and may not fully represent the diverse experiences of all teachers in Malaysia or other regions. Second, the study employed a cross-sectional design, restricting the ability to infer causality between variables. Third, the use of purposive sampling, though justified for expert insights, limits the generalizability of the findings. Lastly, the study relies on self-reported data, which may be influenced by social desirability bias or inaccurate self-assessments, particularly regarding technology engagement and readiness. Future studies should consider longitudinal research designs to examine changes in teaching effectiveness over time as Metaverse technologies are adopted more widely. Expanding the sample to include TVET teachers from different countries or regions could enhance the generalizability and cross-cultural applicability of the findings. Additionally, qualitative approaches such as interviews or case studies could offer deeper insights into the lived experiences of teachers using Metaverse tools, particularly regarding challenges, resistance, and institutional support mechanisms. Future research might also explore the role of student outcomes and feedback in validating teaching effectiveness, offering a more comprehensive evaluation of immersive learning impacts. Finally, incorporating other theoretical models such as the Unified Theory of Acceptance and Use of Technology (UTAUT) or Diffusion of Innovations (DOI) may enrich our understanding of the adoption and sustainability of Metaverse technologies in vocational education.

CONCLUSION

This study has successfully developed and validated a novel research model that integrates teacher development dimensions with teaching effectiveness in the Metaverse context, specifically within the underexplored realm of TVET education. By situating the model within the TPACK framework, the research emphasizes the intertwined significance of professional development, pedagogical training, and teacher readiness in enhancing teaching outcomes through immersive technologies. The empirical findings underscore that while not all components, such as Metaverse tools engagement, yielded significant direct effects, the overall framework provides a solid foundation for understanding how teachers can be empowered to adopt and excel in Metaverse-enhanced instructional settings.

The implications extend beyond academic theory, offering a roadmap for education stakeholders and policymakers to align digital transformation strategies with teacher development programs that are immersive, relevant, and future-ready. As education systems continue to adapt to the demands of the 4IR, this study positions Metaverse integration not as a technological novelty but a strategic enabler of pedagogical innovation and vocational relevance. Ultimately, the research lays the groundwork for sustained inquiry into immersive education technologies, calling for broader empirical exploration, policy support, and institutional readiness to realize the full potential of Metaverse-based teaching in TVET and beyond.

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