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The Effectiveness Of Metaverse System Technology Based On Heavy Machine Virtual Tour

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Abstract
This study evaluated the effectiveness of Metaverse technology in heavy machinery training based on virtual tours. The study used a quasi-experimental design involving 60 students from the Faculty of Technical and Vocational Education (FPTV), Universiti Tun Hussein Onn Malaysia (UTHM), who were divided into an experimental group (Metaverse training) and a control group (conventional training). Data were collected using pre- and post-training questionnaires and analyzed using paired t-tests. These results suggest that the experimental group performed significantly better after the intervention compared to the control group. This study suggests that metaverse system technology based on heavy machine virtual tour can be an effective alternative training method in technical fields, especially heavy machinery operation.
Keywords: *Metaverse, virtual training, heavy machinery, TVET, effectiveness, 3D simulation.*

1. INTRODUCTION

The emergence of Metaverse and virtual reality (VR) technologies has introduced a new dimension in the field of education (Guan et al., 2024; Nassar et al., 2021). Many studies have evaluated the effectiveness of these approaches in enhancing students' understanding, skills, and safety in high-risk learning environments (Yeganeh et al., 2025; Zhang, 2024). Advances in VR and Metaverse technologies have created new opportunities in technical education, particularly in heavy machinery operation training (Mula et al., 2024; Holuša et al., 2023; Jaya et al., 2025). These technologies enable the delivery of learning content in a more interactive and immersive way, allowing students not only to observe but also to interact with the training environment virtually. This approach to learning content delivery aligns with the needs of 21st-century education, which emphasizes active, self-directed, and student-centered learning experiences.

Conventional training in heavy machinery operation usually involves high costs, accident risks, and logistical constraints such as the availability of machines and suitable training locations. The need to rent real machinery, consume fuel, and manage trainees' safety makes this form of training less efficient in terms of both cost and time. In addition, traditional training is often difficult to adapt to individual abilities, as its approach tends to be more general and instructor-centered. The use of Metaverse systems offers an effective alternative solution through virtual simulations that closely resemble real-world conditions (Lee et al., 2022; Damaševičius & Sidekerskienė, 2024; Sghaier et al., 2022). Within this virtual environment, trainees can acquire critical technical skills in a safe, flexible, and accessible manner at any time without the need for real machinery. These virtual simulations can also be tailored to the learners' skill levels, thereby enhancing the effectiveness of learning progressively.

There remains a lack of empirical studies evaluating the effectiveness of Metaverse-based training in the context of TVET students within higher education institutions in Malaysia. This study seeks to examine the extent to which virtual training through the Metaverse can enhance learning achievement, safety levels, and students' experiences in heavy machinery operation. Oje et al. (2023) emphasized that the integration of VR technology can enrich engineering education by providing immersive learning experiences and supporting alternative laboratory settings without replacing traditional in-person laboratories. This view is supported by Oubibi and Hryshayeva (2024), who found that the use of VR facilitates deeper content understanding, increases student engagement, and promotes a more comprehensive grasp of learning experiences. Similarly, Li et al. (2025) demonstrated the notable appeal and effectiveness of VR in architectural history education, while Taghian et al. (2023) reported that AR is set to significantly impact all areas of orthopedics, particularly spinal surgery. In the Malaysian context, Mat Nayan et al. (2024) revealed that both students and teachers show strong interest in adopting VR technology in the education sector. Furthermore, the interactive elements of simulations help students engage with the material in a more enjoyable and meaningful way. Nevertheless, the central issue that emerges concerns whether

Metaverse-based training can truly surpass conventional methods in terms of effectiveness. While the technology exhibits substantial promise, rigorous empirical validation, particularly within Malaysia's technical and vocational education context, remains scarce.

Therefore, this study is conducted to evaluate and compare the effectiveness of Metaverse-based virtual training systems with traditional approaches in terms of learning, safety, user experience, and student motivation. However, most existing studies remain focused on art education, secondary schools, engineering education, and the medical field. Specific research that examines the effectiveness of the Metaverse in the context of heavy machinery operation is still very limited. Hence, this study will make a significant contribution to addressing the existing literature gap, particularly in relation to immersive learning approaches for heavy machinery training among technical education students in Malaysia.

i. To evaluate students' understanding and skill development through immersive training.
ii. To compare the effectiveness between traditional and Metaverse-based methods.
iii. To develop a Metaverse-based virtual tour system for selected heavy machinery.

2. RESEARCH METODOLOGI

2.1 Research Design

This research employed a quasi-experimental design involving two groups, namely the experimental and the control group. The experimental group received training using the Metaverse system, while the control group underwent conventional training through traditional methods. This design was chosen as it is appropriate for comparing the effects of Metaverse technology on students' understanding, skills, and perceived training effectiveness.

2.2 Population and Sampling

The study population consisted of students from the Faculty of Technical and Vocational Education (FPTV), Universiti Tun Hussein Onn Malaysia (UTHM). A total of 60 students were selected through purposive sampling, with 30 students assigned to the experimental group and another 30 students placed in the control group.

Table 1: Research Respondents

No	Demography		Group			
			Experiment		Control	
			Frequency	Percent	Frequency	Percent
1	Gender	Male	26	86.7	27	90.0
		Female	4	13.3	3	10.0
2	Age	21-24	25	83.3	24	80.0
		25-30	5	16.7	6	20.0
3	Year of Study	Year 2	24	80.0	25	83.3
		Year 3	16	20.0	5	16.7
4	Experience in Operating Heavy Machinery	Yes	9	30.0	10	33.3
		No	21	70.0	20	66.7
5	Level of Computer / VR Skills	High	9	30.0	8	26.7
		Moderate	14	46.7	16	53.3
		Low	7	23.3	6	20.0

2.3 Data Collection Instrument

The research instrument was a questionnaire developed based on three main dimensions: Section B (Understanding and Skills), Section C (Perceived Effectiveness of the Training), and Section D (Metaverse System Evaluation). All items were measured using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). A pilot study was conducted to assess the suitability and reliability of the questionnaire before its actual use, involving 30 student respondents from FPTV, UTHM.

Table 2: Pilot Study

Section		Items	Mean (M)	Standard Deviation (SD)	Cronbach's Alpha (α)	Reliability Level
Section B: Understanding and Skills	Pre	15	48.53	6.53	0.938	Very High
	Post	15	57.60	12.22	0.949	Very High
Section C: Perceived Effectiveness of the Training	Pre	5	15.43	2.13	0.963	Very High
	Post	5	18.28	5.22	0.971	Very High
Section D: Metaverse System Evaluation		24	67.45	43.86	0.979	Very High

The pilot study was conducted to evaluate the clarity, training effectiveness, and Metaverse system assessment prior to the actual research. Overall, the findings indicated that the reliability of the instrument was at a high and satisfactory level. Each section of the questionnaire was tested using reliability analysis (Cronbach's Alpha) and basic descriptive statistics (mean and standard deviation). The results showed that all three sections demonstrated high reliability, with Cronbach's Alpha values exceeding 0.90. This confirms that the questionnaire items were consistent and suitable for use in the main study.

Data Collection Procedure

The data collection procedure involved several steps. First, students were divided into two groups, namely the experimental and control groups. A pre-test was then conducted to assess their initial level of understanding and skills. The experimental group underwent training using the Metaverse system, while the control group participated in conventional training. Finally, a post-test using the same questionnaire was administered to evaluate changes in understanding, training effectiveness, and user experience with the system.

2.4 Data Analysis

Descriptive analysis, including mean, standard deviation, and frequency, was used to summarize demographic information and students' perceptions. Reliability analysis was conducted using Cronbach's Alpha to evaluate the internal consistency of the instrument. Inferential analysis was performed using the independent samples t-test to compare differences between the experimental and control groups.

Table 3: Mapping of Research Objectives to Questionnaire Sections

Objective	Group	Phase	Statistical Analysis
i – Evaluate understanding & skills	Experimental & Control	Pre & Post	Independent sample t-test
ii – Keberkesanan	Experimental & Control	Post	Independent sample t-test
iii – Develop the Metaverse system	Experimental	Post	Descriptive statistics (mean, SD), Reliability (Cronbach's Alpha)

2.5 Ethical Considerations

This study adhered to research ethics guidelines by considering several aspects. Informed consent was obtained from all respondents before the study was conducted, and the confidentiality of respondents' data was ensured, with the information used solely for academic purposes. There were no risks of physical or psychological harm to respondents, as the training was conducted in a controlled environment. In addition, official approval was obtained from FPTV UTHM to carry out the research.

3. FINDINGS AND DISCUSSION

The demographic analysis shows that both the experimental and control groups were relatively homogeneous, which supports the reliability of group comparisons (Creswell, 2009; Jager et al., 2017). Male students dominated both groups, which is common in technical and vocational fields related to heavy machinery. The majority of respondents were within the typical undergraduate age range (21–24 years), and most were in their second year of study, suggesting they were at an early stage of developing technical competencies. Notably, most students lacked prior experience in operating heavy machinery, aligning with findings that novice learners benefit significantly from simulation-based training due to reduced safety risks and cost implications. Meanwhile, the majority reported moderate levels of computer and VR skills. This is an important factor, as digital literacy has been shown to influence students' readiness to engage with immersive learning technologies. Overall, the demographic balance between groups minimizes the risk of bias and increases the validity of conclusions regarding the effectiveness of Metaverse-based training compared to traditional methods.

3.1 To evaluate students' understanding and skill development through immersive training

To evaluate students' understanding and skill development through immersive training, an independent samples t-test was conducted to compare the pre-test scores (BC_PRE) between the experimental and control groups. The results of the analysis are presented in Table 5.

Table 5: Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	95% Confidence Interval of the Difference	
							Lower	Upper
BC_PRE	Equal variances assumed	0.245	0.622	0.811	58	0.421	-0.14199	0.33533
	Equal variances not assumed			0.811	57.862	0.421	-0.14200	0.33534

The results of the independent samples t-test for the pre-test scores (BC_PRE) showed no significant difference between the experimental group and the control group, $t(58) = 0.811$, $p = 0.421$. Levene's test indicated that the assumption of equal variances was met ($F = 0.245$, $p = 0.622$). The mean difference between the groups was very small and not statistically significant, with a 95% confidence interval ranging from –0.142 to 0.335. These findings suggest that both groups had a comparable level of understanding and skills at the beginning of the study, confirming that the groups were equivalent prior to the training intervention. The findings are consistent with the study by Nirmala et al. (2022), where the researchers ensured that the experimental and control groups were equivalent before the intervention. In their study on technology-enabled learning among teacher education trainees, Nirmala et al. (2022) employed an experimental design with pre-test and post-test and found that the pre-test scores between the experimental and control groups did not differ significantly. This indicated that the groups were homogeneous prior to the intervention.

3.2 To compare the effectiveness between traditional and Metaverse-based methods.

To compare the effectiveness of traditional and Metaverse-based training methods, an independent samples t-test was conducted on the post-test scores (BC_POST) of the experimental and control groups. The results of the analysis are presented in Table 6.

Table 6: Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Sig. (2-tailed)	95% Confidence Interval of the Difference	
						Lower	Upper

BC_POST	Equal variances assumed	8.412	0.005	11.283	58	0.000	1.17220	1.67780
	Equal variances not assumed			11.283	46.077	0.000	1.17080	1.67920

The independent samples t-test result for the post-test scores (BC_POST) revealed a significant difference between the experimental group and the control group, $t(58) = 11.283$, $p < 0.001$. Levene's test indicated unequal variances ($F = 8.412$, $p = 0.005$); however, the t-test remained highly significant under both assumptions. The 95% confidence interval of the difference ranged from 1.17 to 1.68, confirming that students in the experimental group who underwent Metaverse-based training achieved significantly higher levels of understanding and skills compared to those in the traditional training group. These findings suggest that the Metaverse-based approach was more effective in enhancing learning outcomes. This finding is consistent with the study of Onu et al. (2024), which also highlighted the superiority of immersive and virtual approaches compared to traditional teaching methods. Onu et al. (2024) reported that the use of Metaverse technologies in education can lead to improved learning outcomes and increased engagement, particularly when contrasted with conventional classroom-based instruction. This alignment indicates that the significant post-test differences observed in the present study are not isolated, but rather form part of a broader body of empirical evidence supporting the effectiveness of Metaverse-based interventions in enhancing student understanding and skills.

3.3 To develop a Metaverse-based virtual tour system for selected heavy machinery.

To address Objective 3 of the study, an analysis of the usability of the Metaverse-based virtual tour system was conducted using the items in Section D of the questionnaire. This analysis aimed to evaluate the usability level of the system from the users' perspective and to ensure that the instrument employed was consistent and reliable. Accordingly, the overall mean, variance, standard deviation, and Cronbach's Alpha reliability coefficient were calculated to determine the internal consistency of the instrument as well as the overall effectiveness of the system. The analysis results are presented in Table 4 below.

Table 4: Scale and Reliability Statistics for Usability

No	Statistics	Value
1	Mean (Total Score)	103.90
2	Variance	34.51
3	Standard Deviation	5.87
4	Number of Items	24
5	Cronbach's Alpha	0.891

Based on Table 4, the overall mean score was 103.90 with a standard deviation of 5.87, indicating a good level of response consistency among participants. The moderate variance (34.51) suggests that the data were not widely dispersed, reflecting a uniform perception of the usability of the Metaverse-based virtual tour system. The Cronbach's Alpha value of 0.891 was very high, exceeding the commonly accepted minimum threshold of 0.70 in educational and social research. This value demonstrates that the questionnaire possessed strong internal consistency, confirming that the instrument was stable and reliable for assessing user experience. Recent studies have also emphasized that a Cronbach's Alpha value above 0.80 is a strong indicator that a scale can consistently produce reliable results across items and respondents. Overall, these findings confirm that the set of items in Section D was appropriate for measuring the usability of the developed Metaverse system and provides a solid foundation for addressing the research objective related to user experience.

The present findings further support the results reported by Bayram and Temel (2025), who demonstrated that the Metaverse Scale achieved a very high Cronbach's Alpha of 0.90, confirming its reliability in measuring perceptions of the Metaverse. Similarly, the Cronbach's Alpha value of 0.891 obtained in this study indicates that the instrument used to assess usability in the Metaverse-based virtual tour system was both stable and internally consistent. This parallel outcome reinforces the argument that Metaverse-related constructs can be measured with strong reliability across different contexts and

populations. Furthermore, Bayram and Temel (2025) found that students' knowledge, attitudes, and awareness of the Metaverse significantly influenced their expectations of decent work in the future, with the Metaverse scale explaining 18% of the variance in those expectations. In line with this, the uniform perception of usability identified in the present study, as reflected by the moderate variance (34.51), suggests that participants consistently viewed the system as usable and beneficial. Taken together, these findings highlight that positive and reliable user experiences with Metaverse technologies in educational settings not only validate the robustness of the measurement tools employed but also provide empirical support for the broader implications outlined by Bayram and Temel (2025), namely, that young generations' positive perceptions of the Metaverse can shape their outlook on future employment and workplace adaptability.

To evaluate the usability level of the developed Metaverse-based virtual tour system, a descriptive analysis was conducted on the 24 items in Section D of the questionnaire. This analysis employed mean and standard deviation to identify respondents' perceptions of functionality, ease of use, and overall experience while interacting with the system.

Table 8: Descriptive Analysis of the Usability Level of the Metaverse-Based Virtual Tour System

Item	Mean	SD	Level	Item	Mean	SD	Level
D1	4.10	0.31	High	D13	4.37	0.49	High
D2	4.10	0.31	High	D14	4.53	0.51	High
D3	4.10	0.31	High	D15	4.40	0.50	High
D4	4.23	0.43	High	D16	4.40	0.50	High
D5	4.23	0.43	High	D17	4.53	0.51	High
D6	4.30	0.47	High	D18	4.53	0.51	High
D7	4.30	0.47	High	D19	4.47	0.51	High
D8	4.30	0.47	High	D20	4.50	0.51	High
D9	4.20	0.41	High	D21	4.43	0.50	High
D10	4.20	0.41	High	D22	4.40	0.50	High
D11	4.33	0.48	High	D23	4.37	0.49	High
D12	4.37	0.49	High	D24	4.20	0.41	High

Based on Table 8, the analysis of mean and standard deviation indicates that the usability level of the Metaverse system was at a high level (overall M = 4.30, SD = 0.46). This finding suggests that respondents perceived the developed system as easy to use, user-friendly, and effective in supporting the learning experience. Specifically, the items with the highest scores were D14, D17, and D18 (M = 4.53, SD = 0.51), which were closely related to comfort of use, clarity of navigation, and overall system functionality. This shows that the system successfully provided students with a smooth and engaging learning experience. On the other hand, the lowest-scoring items were D1 to D3 (M = 4.10, SD = 0.31), although still rated at a high level. This indicates that there is some room for improvement in the basic aspects of initial system use, such as interface introduction and getting-started guidance. Overall, these findings are consistent with previous studies, which emphasized that Metaverse-based systems have the potential to enhance learning effectiveness through interactivity, usability, and efficiency (Pyae et al., 2023). Therefore, the developed system not only reduces the costs and risks associated with physical heavy machinery training but also provides a more effective, immersive, and self-directed learning environment for technical students.

4. CONCLUSION

This study investigated the effectiveness of a Metaverse-based virtual tour system for heavy machinery training by examining three main objectives: (i) evaluating students' understanding and skills, (ii) comparing the effectiveness of traditional and immersive approaches, and (iii) assessing the usability of the developed system. The findings revealed several important conclusions. First, the demographic analysis indicated that the experimental and control groups were comparable at the beginning of the

study, thereby ensuring reliable comparisons. Second, the independent samples t-test results demonstrated that while no significant differences existed in the pre-test, the experimental group significantly outperformed the control group in the post-test, confirming the effectiveness of Metaverse-based training in enhancing students' understanding and technical skills. Third, the usability analysis indicated that the developed system achieved a high level of user acceptance, with strong reliability and consistent positive feedback on functionality, ease of use, and learning support. Taken together, these results provide empirical evidence that integrating Metaverse technologies into technical and vocational training can significantly enhance learning outcomes, improve safety, reduce costs, and create a more engaging educational experience.

Based on the findings, several recommendations are proposed for future practice and research:

i. Integration into Curriculum: Technical and vocational institutions should consider incorporating Metaverse-based systems into their teaching and learning practices, particularly in high-risk and cost-intensive areas such as heavy machinery training.

ii. System Enhancement: Although overall usability was high, improvements can be made in the initial interface introduction and system navigation guidance to further support novice users.

iii. Teacher Training and Support: Lecturers and instructors should be trained in immersive technology pedagogy to ensure effective facilitation and integration of Metaverse systems into the classroom.

iv. Scalability and Customization: Future developments should explore expanding the system to cover a wider range of machinery and allow customization to suit different skill levels, thus enhancing its applicability across diverse vocational contexts.

v. Longitudinal Research: Future studies could adopt a longitudinal design to examine the long-term impacts of Metaverse-based training on students' retention, transfer of skills to real-life practice, and employability outcomes.

vi. Comparative Studies Across Disciplines: Further comparative research is recommended to explore the effectiveness of Metaverse applications in other technical, engineering, and health-related fields, thereby strengthening the generalizability of the findings.

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