Seminars in Medical Writing and Education. 2025; 4:829
doi: 10.56294/mw2025829

ORIGINAL

Harnessing Metaverse-Driven Project-Based Learning in TVET: Elevating Higher-Order Thinking Skills for the Future Workforce

Aprovechamiento del Aprendizaje Basado en Proyectos impulsado por el Metaverso en la FP: Potenciando las Habilidades de Pensamiento de Orden Superior para la Fuerza Laboral del Futuro

Sukardi[1], Oriza Candra[1], Mahesi Agni Zaus[1], Bulkia Rahim[1], Syaiful Islami[1], Yee Mei Heong[2]

[1]Universitas Negeri Padang, Technical and Vocational Education. Padang, Indonesia.
[2]Universiti Tun Hussein Onn Malaysia, Technical and Vocational Education, Johor, Malaysia.

Citar como: Sukardi, Candra O, Agni Zaus M, Rahim B, Islami S, Heong YM. Harnessing Metaverse-Driven Project-Based Learning in TVET: Elevating Higher-Order Thinking Skills for the Future Workforce. Seminars in Medical Writing and Education. 2025; 4:829. https://doi.org/10.56294/mw2025829

Submitted: 15-04-2025 **Revised:** 20-07-2025 **Accepted:** 22-10-2025 **Published:** 23-10-2025

Editor: PhD. Prof. Estela Morales Peralta

Corresponding author: Syaiful Islami

ABSTRACT

The fast evolution of the immersive digital technologies has changed education and brought about new possibilities of interactive and experiential learning. One of those innovations is the Metaverse, which can be used to provide an experience of real-life virtual environments that can improve engagement and collaboration, although its pedagogical applications in vocational education are less explored. Addressing the demand of graduates with the advanced skills of analytical, creative and problem-solving, this research paper explores how the Metaverse-based Project-Based Learning (PjBL) can enhance Higher-Order Thinking Skills (HOTS) in students of Technical and Vocational Education and Training (TVET). Quasi experimental design was used with pre-test and post-test control groups to compare the results of Metaverse-integrated and traditional PjBL. The learning gains in the students were measured by collecting data using a HOTS assessment test and analyzing them using both descriptive and inferential statistical techniques. Findings show that the students in the Metaverse group made significantly better improvement in HOTS especially in analysing, evaluating and creating dimensions than the students in the control group. These results prove that PjBL with the implementation of the Metaverse contributes to better intellectual results among students and greater involvement in the educational process.Regardless of the difficulties concerning the infrastructure and instructor preparation, the research finds that Metaverse-powered PjBL is a powerful instructional framework to develop 21 st -century skills in the TVET education.

Keywords: Metaverse; Project-Based Learning; TVET; Higher-Order Thinking Skills; Future Workforce.

RESUMEN

La rápida evolución de las tecnologías digitales inmersivas ha transformado la educación y ha generado nuevas posibilidades de aprendizaje interactivo y experiencial. Una de estas innovaciones es el Metaverso, que puede utilizarse para ofrecer experiencias virtuales realistas capaces de mejorar la participación y la colaboración, aunque sus aplicaciones pedagógicas en la educación vocacional siguen siendo poco exploradas. Atendiendo a la necesidad de formar egresados con habilidades avanzadas de análisis, creatividad y resolución de problemas, esta investigación examina cómo el aprendizaje basado en proyectos (PjBL) impulsado por el Metaverso puede fortalecer las habilidades de pensamiento de orden superior (HOTS) en estudiantes de Educación y Formación Técnica y Profesional (TVET). Se empleó un diseño cuasi-experimental con grupos de control de pretest y postest para comparar los resultados del PjBL integrado en el Metaverso con el PjBL tradicional. Los avances en el aprendizaje se midieron mediante una prueba de evaluación de HOTS y se analizaron utilizando técnicas estadísticas descriptivas e inferenciales. Los resultados muestran que los estudiantes del grupo del Metaverso obtuvieron mejoras significativamente mayores en HOTS, especialmente en las dimensiones de análisis, evaluación y creación. Estos hallazgos demuestran que la integración del Metaverso en el PjBL favorece un rendimiento intelectual superior y una mayor implicación en el proceso educativo. A pesar de los desafíos relacionados con la infraestructura y la preparación docente, el estudio concluye que el PjBL potenciado por el Metaverso constituye un marco pedagógico eficaz para desarrollar las competencias del siglo XXI en la educación TVET.

Palabras clave: Metaverso; Aprendizaje Basado en Proyectos; Formación Profesional; Habilidades de Pensamiento de Orden Superior; Fuerza Laboral del Futuro.

INTRODUCTION

The appearing of digital technologies and the fast development of innovation in the Fourth Industrial Revolution have completely changed human life. Society 5.0 transition focuses on the inclusion of technology in the social and economic framework, education included. The educational organizations must therefore react to these changes by embracing new pedagogical frameworks that are relevant to the digital age. In this regard, immersive technologies have made novel possibilities of an interactive and experiential learning that transcends the traditional classroom boundaries. The Metaverse is one of the most recognized innovations that created a virtual three-dimensional space where people can interact via digital avatars in real-time. It was invented by Neal Stephenson in 1992 and developed on the early virtual platforms like Second Life in the early 2000s.(1) As virtual reality (VR), augmented reality (AR), and blockchain technologies continue to evolve, the Metaverse has transformed into a fully-fledged digital ecosystem, and it can be greatly used in education. In the educational sector, it provides an opportunity to develop realistic and cooperative learning which is hard to accomplish physically.(2,3)

Technical and Vocational Education and Training (TVET) has a significant role of equipping the workforce to gain competence and adaptability to meet the demands of the new labor market. Vocational education must not just impart students with technical skill but also mental and creative skill, especially Higher-Order Thinking Skills (HOTS) of analysis, assessment, and invention. These abilities are needed to deal with the progressively multifaceted and interdisciplinary issues that define the industrial and technological landscapes. Nonetheless, the traditional modes of teaching do not always have the capacity to contribute to such abilities, since the process of learning is usually oriented to the processes rather than to the imaginative use and solutions to the problems.(4,5,6) Project-Based Learning (PjBL) is one of the pedagogical methods that have been embraced extensively to eliminate these difficulties. The approach focuses on the participative nature of learners in the problem solving activities of real-life problems by following systematic steps, such as problem orientation, project design, project implementation, presentation and reflection. PjBL promotes teamwork, critical thinking, and creativity and enhances the motivation of students and their engagement. However, the traditional applications of PjBL are still limited by the space, time, and institutional resources that restrict the authenticity and diversity of the project experiences. With the implementation of the Metaverse into PjBL, new opportunities to overcome these limitations emerge. With the help of immersive simulations, students will be able to design and execute projects that are representative of industrial settings in the real-world, without being constrained by physical boundaries. They are able to hold communication, work together and to show their work in the same virtual space which can help to increase the participation and creativity. Research has shown that the Metaverse encourages a higher level of intrinsic motivation and cognitive learning in learners. Regardless of this promise, the research on the efficacy of Metaverse-based PjBL, especially in the context of the TVET and its effects on HOTS, is scanty.(7,8) The given research gap demonstrates a necessity to conduct empirical research, which would evaluate the pedagogical potential of the Metaverse in vocational education. Digital economy requires graduates with both technical and critical and innovative thinking. Thus, the TVET institutions need to implement progressive pedagogies that embrace digital immersion to enhance the learning outcomes. The PjBL in the metaverse is a newer approach to instruction, as it fits these goals and, in addition, fosters learning depth and a practical approach.(9,10,11,12) The proposed research will investigate the success of the idea of Project-Based Learning (PjBL) using the Metaverse to enhance Higher-Order Thinking Skills (HOTS) among students undergoing Technical and Vocational Education and Training (TVET) as a quasi-experimental study design that presupposes comparison between two types of PjBL, i.e., Metaverse and conventional. The premise behind this research is that there is an increasing call to modernize vocational education in accordance with the current trends in technology, as well as in accordance with the demands of the workforce.(13,14,15) Metaverse-created PjBL can break down the traditional constraints, achieve more effective learning, and develop the problem-solving, analytical, and creative skills needed to succeed in the 21st-century work environment by introducing immersion environments to project-based teaching.[16,17]

METHOD

Research Design

This study is a non-observational, quantitative and quasi-experimental study that will utilize the pre-test and post-test control group design to establish the efficacy of Metaverse-based Project-Based Learning (PjBL) in improving Higher-Order Thinking Skills (HOTS) among students in Technical and Vocational Education and Training (TVET) programs. The quasi-experimental method would be used since the subjects were not recruited into random groups but instead assigned to the available classes. The design of the research involved students studying at one of a diploma level TVET institution in Indonesia in the 2024/2025 academic year. Purposive sampling was done to select two intact classes of the same study program. The experimental group (n = 35) was guided by Metaverse-based PjBL and the control group (n = 35) by using standard PjBL without integrating it with the Metaverse. The instructor in both groups was to ensure that the quality of teaching and standards of assessment remained consistent. The instructional method was an independent variable, which included Metaverse-based and standard PjBL, whereas such indicators as analyzing, evaluating, and creating served as an indicator of the HOTS in students. The HOTS assessment test which was developed under the revised Bloom Taxonomy and had essay and multiple choice items, was used to collect the data, which was designed to provide measurement of analytical, evaluative and creative thinking. Both groups were given the same instrument both prior to the intervention and after it. The quantitative data were compared with descriptive statistics (mean, standard deviation, and percentage gain) and inferential statistics, paired sample t-tests within-groups and independent sample t-tests between-groups, which were conducted using SPSS version 26.0. The research was conducted under ethical research guidelines, and permission was taken by the institution before data was gathered. The study aim was mentioned to the participants who then gave voluntary consent, and a guarantee of confidentiality was given to them, and no personal identity was released during the reporting.

Research Participants

This study is a non-observational, quantitative, quasi-experimental study that uses the pre-test and control group in analyzing the effectiveness of the Metaverse-based Project-Based Learning (PjBL) in developing Higher-Order Thinking Skills (HOTS) in students in Technical and Vocational Education and Training (TVET) programs. The sample was 70 TVET students divided into two intact classes of 35 students each. Metaverse-integrated PjBL was used to teach the experimental group, and traditional PjBL was applied to teach the control group. The groups were chosen according to the already existing classes, which corresponds to the nature of quasi-experimental design, when it is impossible to randomly assign groups. All participants had common academic backgrounds and general digital literacy, which supported reducing the possibility of bias in the impact of the treatment. Purposive sampling method was used to sample the two classes in the same study program to provide comparability of people sampled. The same instructor was taught both groups so that they could be consistent in the levels of instructional delivery and assessment.

Data Gathering Procedures

Two instruments were used in the collection of the data: a Higher-Order Thinking Skills (HOTS) Assessment Test and a Student Perception Questionnaire. The HOTS test was conducted on the students before (pre-test) and after (post-test) the intervention in order to assess their higher-order thinking skills, namely, analyzing, evaluating, and creating, when measured on the new Bloom Taxonomy.[18,19,20] Problem-solving and essay questions were the test items which were based on the already existing validated HOTS frameworks and were adjusted to the TVET context. The test was tested on content validity and the three experts on educational assessment and instructional design confirmed the content validity. The specialists revised the test questions in accordance with the HOTS indicators, clarity of the language, and conformity to the learning goals.[21,22] The measures of reliability were achieved by pilot testing on an analogous group of students and the internal consistency was gauged by Cronbachs Alpha. A self-administered tool that was given to students after the intervention was the Student Perception Questionnaire that contained the thoughts of students in regards to their learning experience. It used five-point Likert questions with open-ended questions.The closed-ended questions were used to evaluate such dimensions as motivation, collaboration and creativity, whereas the open questions allowed to extract the information of the qualitative nature related to the experience of the students in the Metaverse-based learning environment. The intervention was conducted during one semester (14 weeks) where both groups had the same project theme but in different environments: the experimental group used a Metaverse platform where they collaborated, and the control group did the projects in a conventional classroom setting.

Data Analysis

A quantitative approach was adopted in the data analysis in this research. Paired sample t-tests were initially applied to determine the change in pre-test and post-test outcomes in each group to determine the advancement of HOTS. Then, independent sample t-tests were performed to identify the difference between the experimental group that underwent Metaverse-powered PjBL and the control group that underwent conventional PjBL instruction. Moreover, the effect size (Cohen d) was estimated to determine the size of the treatment effect. The descriptive statistics such as the mean scores, standard deviations, and gain scores were also presented to offer the complete overview of the performance patterns of students. Using such an analytical approach, the paper gives a comprehensive quantitative description of the effectiveness of PjBL based on the Metaverse to increase higher-order thinking skills (HOTS) among TVET learners. Every research practice was conducted in line with ethical guidelines of educational research. The academic ethics committee of the participating institution gave the consent to carry out the study. Informed consent was also given to the participants to explain the purpose of the study, the protocols that would be followed, and their free will to exit the study without repercussions. All the participants were informed and were provided with informed consent, and no personal information was revealed during the process of data handling and reporting. There was no collection of any personal identifying information and all the results were presented in aggregate form to guarantee the anonymity of the participants and to adhere to the ethical standards of the institution.

RESULT

The outcome showed that all distributions were normal whereby p-values were between 0,112 to 0,267 (p > 0,05). The findings indicated that there are no significant differences in variances between the pre-test (F = 0,327, p = 0,569) and the post-test scores (F = 1,284, p = 0,261). In this way, the conditions of homogeneity of variances were met. These initial tests confirm that parametric statistical tests, such as paired sample t-tests and independent sample t-tests were used further.

Table 1. Normality Test (Shapiro-Wilk)

Group	Test	Statistic	df	Sig. (p)
Experimental Pre	Shapiro-Wilk	0,978	35	0,176
Experimental Post	Shapiro-Wilk	0,982	35	0,211
Control Pre	Shapiro-Wilk	0,975	35	0,112
Control Post	Shapiro-Wilk	0,981	35	0,267

Source: Processed data from HOTS pre-test and post-test results (SPSS 26.0 output, 2025).

Table 2. Homogeneity of Variances (Levene's Test)

Test	F	Sig. (p)
Pre-test	0,327	0,569
Post-test	1,284	0,261

Source: Processed data from HOTS pre-test and post-test results (SPSS 26.0 output, 2025).

Qualitative analysis of pre-test and after-test scores gives a summary of the performance of the students in the experimental and control group (Metaverse-driven PjBL and conventional PjBL), respectively. The mean scores of the two groups in the pre-test indicated that there was a relative equal level in the mean scores of both groups as shown in table 3, which is that both of the groups had the same level of Higher-Order Thinking Skills (HOTS). The experimental group had the average pre-test score of 52,35 (SD = 6,41) and the average score of the control group was 51,78 (SD = 6,87). Such a similarity indicates homogeneity at baseline and preconditions the validity of further comparisons. Clearly, however, after the intervention, differences appeared. The experimental group had a post-test average of 78,92 with a standard deviation of 5,62 whereas the control group had a standard deviation of 68,45 with an average of 68,45. This contrast is further emphasized by the gain scores which are determined by the difference between the post-test and pre-test scores. It was found that the experimental group had a mean of 26,57 and the control group had 16,67.

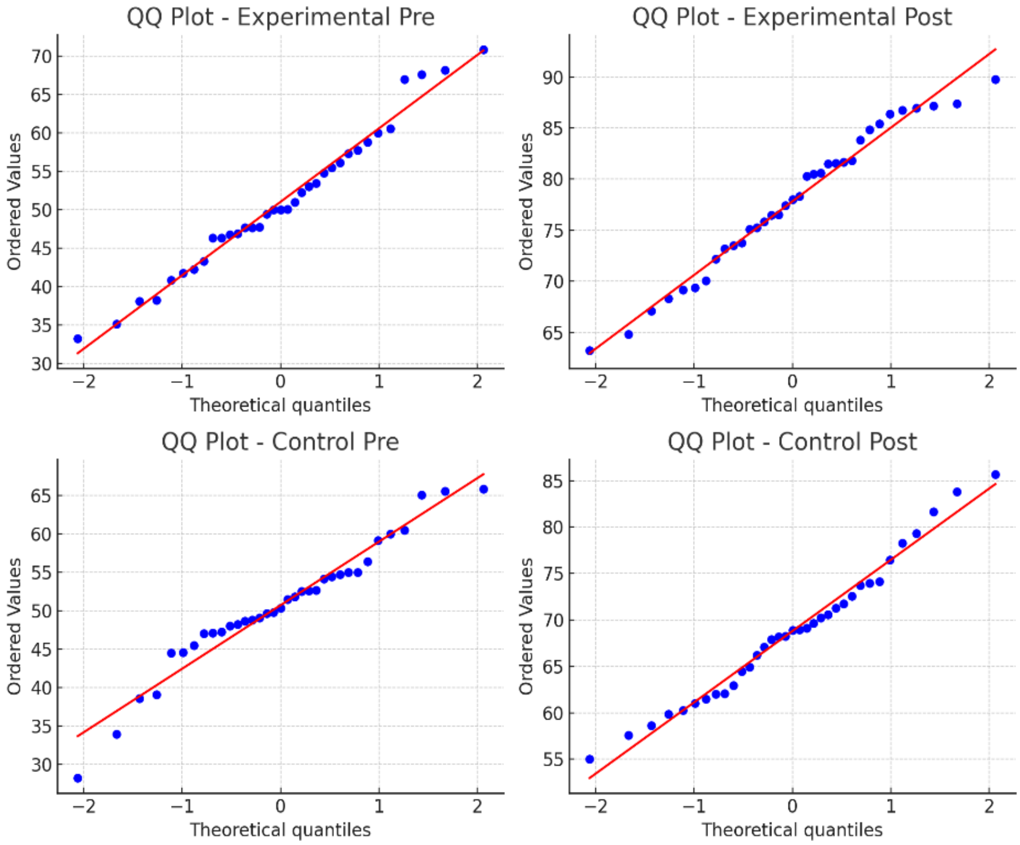

Figure 1. Q-Q Plot
Source: Processed data from HOTS pre-test and post-test results (SPSS 26.0 output, 2025).

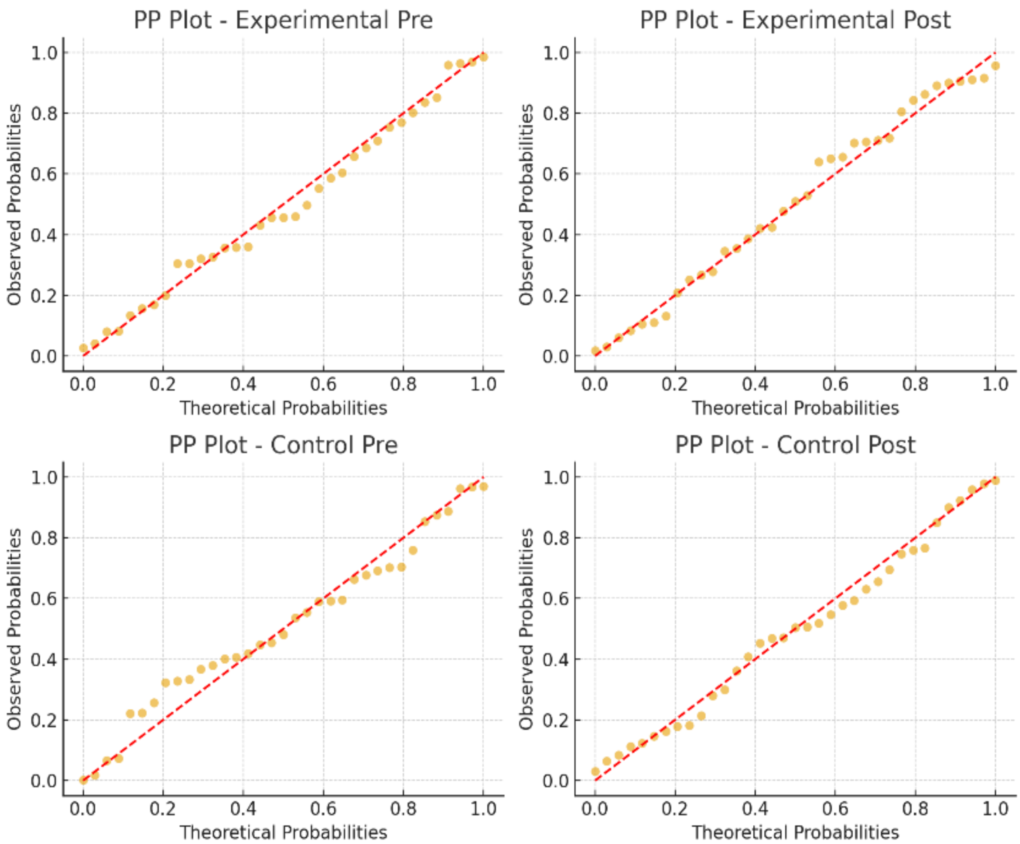

Figure 2. P-P Plot
Source: Processed data from HOTS pre-test and post-test results (SPSS 26.0 output, 2025).

Table 3. Descriptive Statistics of Pre-test, Post-test, and Gain Scores

Group	N	Pre-test Mean (SD)	Post-test Mean (SD)	Gain Mean
Experimental (Metaverse PjBL)	35	52,35 (6,41)	78,92 (5,62)	26,57
Control (Conventional PjBL)	35	51,78 (6,87)	68,45 (6,15)	16,67

Source: Processed data from HOTS pre-test and post-test results (SPSS 26.0 output, 2025).

The paired samples t-test was used to test the differences between the improvement of each group between the pre-test and post-test results. Findings show that there is a significant rise of HOTS in the experimental and the control groups. The extent of improvement was however significantly higher in the experimental group.

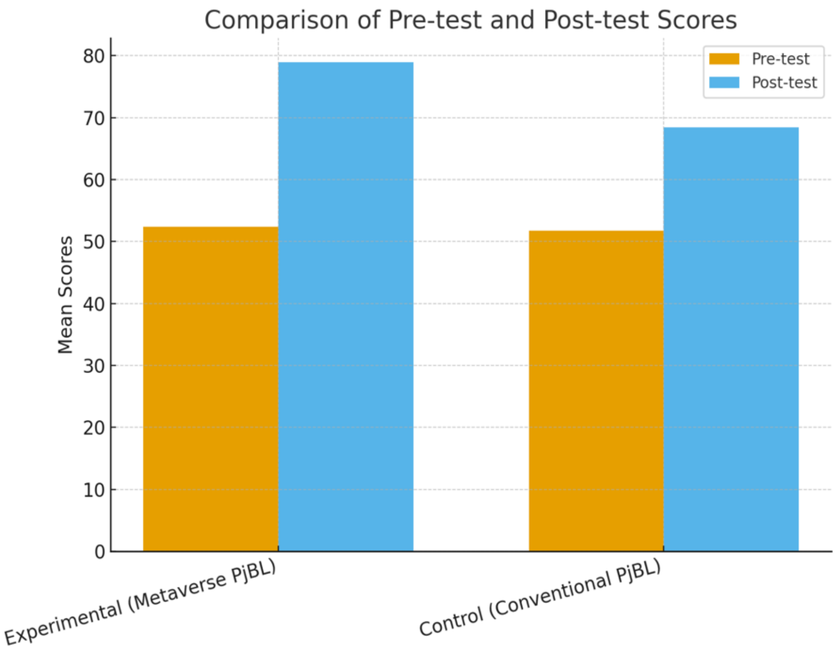

Figure 3. Comparison Pretest and Post Test
Source: Processed data from HOTS pre-test and post-test results (SPSS 26.0 output, 2025).

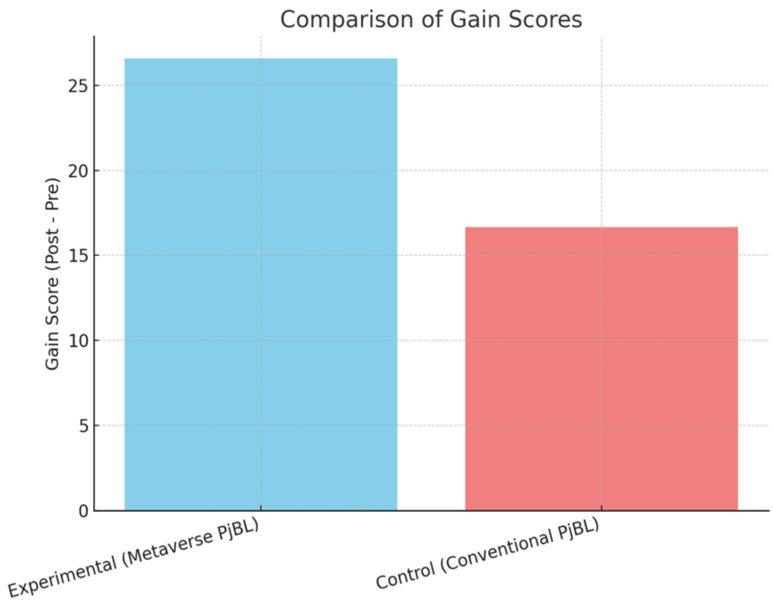

Figure 4. Comparison of Gain Scores
Source: Processed data from HOTS pre-test and post-test results (SPSS 26.0 output, 2025).

Table 4. Paired Samples t-Test Results						
Group	**N**	**Mean Difference**	**t**	**df**	**p-value**	**Cohen's d**
Experimental (Metaverse PjBL)	35	26,57	19,84	34	< 0,001	3,36 (large)
Control (Conventional PjBL)	35	16,67	12,45	34	< 0,001	2,11 (large)
Source: Processed data from HOTS pre-test and post-test results (SPSS 26.0 output, 2025).						

The experimental group ($M = 26,57$) showed a greater improvement than the control group ($M = 16,67$). Both results are significant at $p < 0,001$, with large effect sizes according to Cohen's d, indicating that both teaching methods improved HOTS, but the Metaverse-driven PjBL was more impactful. An independent samples t-test was conducted to compare the post-test scores between the experimental and control groups.

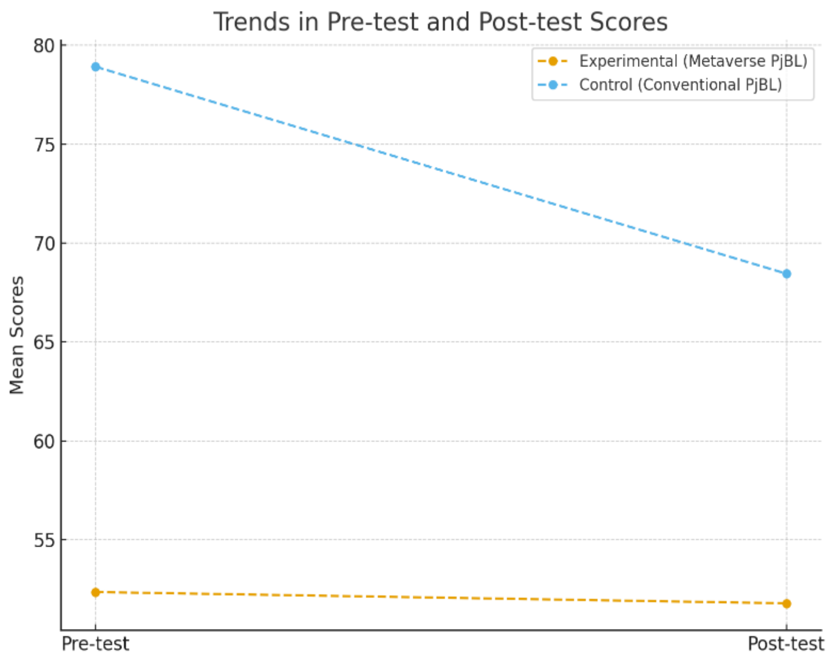

Figure 5. Trends in Comparison of Gain Scores
Source: Processed data from HOTS pre-test and post-test results (SPSS 26.0 output, 2025).

Table 5. Independent Samples t-Test Results					
Test	**Group Means (Post-test)**	**t**	**df**	**p-value**	**Cohen's d**
Post-test Scores	Exp = 78,92, Ctrl = 68,45	6,78	68	< 0,001	1,63 (large)
Source: Processed data from HOTS pre-test and post-test results (SPSS 26.0 output, 2025).					

The results demonstrate a significant difference between the experimental and control groups, $t(68) = 6,78$, $p < 0,001$. The effect size (Cohen's $d = 1,63$) indicates a very large effect, suggesting that Metaverse-driven PjBL was substantially more effective in improving HOTS than conventional PjBL.

DISCUSSION

Findings of this work show that application of Metaverse-based Project-Based Learning (PjBL) has a great effect on improving Higher-Order Thinking Skills (HOTS) among students in Technical and Vocational Education and Training (TVET) institutions.[22,23,24] To be more exact, students in the experimental group had a greater improvement in analyzing, evaluating, and creating skills than their counterparts in the control group. These findings demonstrate that immersive and interactive learning processes have got cognitive benefits over more traditional teaching technologies, and thus, experiential and constructivist approaches to learning are still really applicable in the digital era. This observation is in line with a number of past research studies that have focused on the pedagogical potential of immersive technologies. Still, as an example, a study of radiology and engineering education based on the use of virtual reality revealed that the use of immersive environments could positively affect learners in terms of engagement, conceptual knowledge, and problem-solving capacity in comparison with traditional training. Students who operate in the environment of virtual simulation acquired greater analytical and creative skills, as students could visualize complex processes and could apply abstract ideas in practical application. These findings are essential from the perspective of vocational training as they directly respond to the long-standing issue of filling the gap between theoretical training and practice.[25,26,27,28]

In addition, the current research supports the pedagogical basis of PjBL in the Metaverse. Vygotsky, in his sociological theory of learning, and Kolb, in his experiential model of learning, have both indicated the helpfulness of active participation of students in their construction of knowledge using real and socially mediated experiences as a way of learning.[29,30,31,32,33] These principles are upheld by the Metaverse environment, where students have a virtual environment where they interact with peers, manipulate virtual objects, and reflect on their learning outcomes in real time. The simulated conditions of the industry enabled students to do problem-solving activities, which are close to the real technical problems in other engineering disciplines, like electrical engineering and automotive technology.[34,35,36,37] This result implies that not only is HOTS enhanced in Metaverse-based PjBL, but also professional competencies in Industry 4.0 and Society 5.0 are developed. Although previous studies have determined the beneficial implications of Virtual Reality (VR) and Augmented Reality (AR) regarding the fields of general education and STEM in general, few studies have tested these technologies in vocational education, that intrinsic motivation and long-term retention were afforded by immersive learning, although they also observed a lack of empirical data within TVET institutions.[38,39,40] The present research addresses that gap by offering the quantitative data that validate the effectiveness of immersive environments in the learning of skills. In particular, the quasi-experimental outcomes in this case indicate that it is possible to implement PjBL based on Metaverse even in the resource-restrained learning setting that is typical of most Indonesian vocational schools.[32,41,42]

In addition to the cognitive benefits, the practical benefits of integrating the Metaverse are also found in this research. The instruction, with the help of virtual simulation, allows schools to simulate an industrial situation without expensive infrastructure. This ismore applicable to the developing economies where modern laboratories or industrial machinery are not accessible.[43,44] Reproduction of complex operations in a virtual environment through simulation of real assembly lines, safety activities, or maintenance makes the learners practice the procedures safely and numerous times, decreasing material waste, as well as occupational risk. These advantages are in line with the international trends that advocate green, cost-effective, and inclusive vocational education. However, a number of difficulties arose that need to be overcome to have a wider implementation. Scalability is still hindered by technological limitations in the form of low bandwidth, substandard hardware, and low digital preparedness. Teacher readiness is also a key problem, as unless teachers are properly trained, it is possible that they will not be able to design, manage, and assess immersive PjBL activities. These results resonate with the arguments made by Bower and Radianti et al., who stressed that the success of the immersive learning is due to pedagogical integration, not just the use of technology.[45,46,47] As such, upcoming projects ought to be on the capacity-building of teachers and institutional assistance towards a sustainable implementation of Metaverse-based teaching in vocational programs. Another notable dimension is ethical considerations. Behavioral information, communication, and performance statistics are logged as learners go about in the digital spaces, and this brings into question the issue of privacy and data security. Also, overdependence on computer simulations can decrease exposure of students to the material world and practical practice, which are indispensable in vocational education. The Metaverse, therefore, can be considered another, rather than an alternative, to physical training. The best learning results will be achieved through balanced integration, which implies the combination of immersive simulations with on-the-job workshops. On the whole, the findings of this research are encouraging and give empirical evidence to the adoption of Metaverse-driven PjBL as an innovative teaching method of TVET. The advancement of HOTS, along with the increased rate of student motivation and engagement, suggests that immersive learning can play a significant role in equipping the competent, adaptive, and innovative workforce with the needs of Industry 4.0 and Society 5.0. Hypothetically, this research takes constructivist and experience-based frameworks to a digital-immersive space and provides a framework for assessing technology-enriched learning outcomes.[48] In practice, it provides policymakers, administrators, and educators with a methodically implementable and pedagogically correct introduction to the implementation of immersive technologies in the vocational domain.[49,50] In the future, this study should be extended by exploring the long-term implications of learning in the Metaverse on the aspects of employability, adaptability and life-long learning capabilities. The affordances of immersive technologies to domains may be identified by the comparative analyses of various TVET disciplines. In addition, cross-functional engagements between teachers, business associates, and creators are encouraged in order to make sure that the Metaverse environments will be pedagogically relevant to the work environment and changing economic activities.

CONCLUSION

This paper has shown that the incorporation of the Metaverse-based Project-Based Learning (PjBL) is a marked change in the teaching of vocation especially in the development of Higher-Order Thinking Skills (HOTS) in Technical and Vocational Education and Training (TVET) students. The Metaverse has an effective way of transferring the principles of experiential learning into actual educational practice by immortalizing the learners into realistic, interactive, and constructivist virtual settings. This virtual environment does not only increase the level of engagement and comprehension, but also develops critical, creative, and collaborative skills that are crucial to become successful in Industry 4.0 and the new Society 5.0. This research has brought a new contribution due to its novelty and practical implications. Compared to the majority of the current research, which centers around general or STEM-related education, this research places immersive technology in the under-researched setting of vocational education, where students need to acquire theoretical and technical skills at the same time. The results indicate that virtual environments that can simulate industrial environments are especially significant to TVET learners. By use of the simulations, the learners get to train on the complex tasks safely, work together and be involved in developing the skills without the limitations of the expensive physical setup. Therefore, PjBL based in the Metaverse can be taken as a legitimate and transformational addition to old models of vocational training.

Nevertheless, it is also in this study that critical issues are found that need to be tackled to achieve sustainable adoption. These are infrastructural obstacles like the lack of access to proper equipment and internet access, pedagogical barriers like teacher preparation and curriculum, and ethical issues like privacy of data and fair access to technology. Devoid of strategic institutional planning and support the advantages of Metaverse integration can be left scattered or unevenly spread within the context of education. Theoretically speaking, this study adds theoretical background and a practical road to integrate immersive learning into higher and vocational educational systems. PjBL with metaverse offers a chance to train graduates not merely technically skilled but also able to reason critically, solve problems creatively, and collaborate adaptively, which are the quality peculiar to future-oriented industries. Future studies are needed to expand the results by analyzing longitudinal effects on the ability of learners to be employable, flexible and capable of life long learning and exploring cross-disciplinary uses of immersive technologies.In addition, it will be essential to develop sustainable models of the integration of the Metaverse as an educational policy, curriculum, and teacher improvement process, which will help attain systemic change. Finally, the effective implementation of the Metaverse-based pedagogies will result in a paradigm shift to a more dynamic, inclusive, and future-oriented paradigm of vocational education.

REFERENCES

1. Lee H, Yoo HJ, Ryu H. Utilization of metaverse environment for education among nursing students based on personality traits and digital literacy. Clin Simul Nurs. 2025;107:101801.

2. Roy R, Rao GA, Pal D, Anuradha S, Mukherjee S. Metaverse-based education for sustainable development and improving the performance: discussing the future research agenda. Sustainable Futures. 2025;10:101091.

3. Zhang Y, Kong M, Wang WZ, Deveci M, Bilican MS, Delen D. A multi-criteria decision-making framework for metaverse adoption: evidence from higher education systems. Expert Syst Appl. 2026;296:129132.

4. Aziz F, Li C, Khan AU. Immersive learning in virtual worlds: a two-step analysis SEM and NCA for assessing the impact of metaverse education on knowledge retention and student collaboration. Technol Soc. 2025;81:102871.

5. Singh M, Sun D, Yang Y. Design and implementation of Math City: an inquiry-based metaverse platform for mathematics education. Comput Educ Artif Intell. 2025;9:100462.

6. Oladokun BD, Atuase D, Ajani YA, Tachie-Donkor G, Enakrire RT. Perspectives of librarians on the integration of metaverse into the future information services in higher education institutions. J Acad Librariansh. 2025;51(5):103103.

7. Yannuar Y, Hasan B, Abdullah AG, Hakim DL, Wahyudin D. Design and implementation of web-based internship information system at vocational school. In: IOP Conf Ser Mater Sci Eng. Institute of Physics Publishing; 2018.

8. Aldawsari R, Buhalis D, Roushan G. Immersive metaverse technologies for education and training in tourism and hospitality. Int J Contemp Hosp Manag. 2025;37(8):2716–36.

9. Pardo Ríos M, López López CA, Castro Delgado R, Morales Moreno I, Guillén Martínez D, López Guardiola P, et al. Meta-health: a national SWOT analysis for the development of a metaverse and virtual reality in health sciences education. Teach Learn Nurs. 2025;[Epub ahead of print].

10. Aideed H, Elbayoumi Salem I, Magdy A, AlAmri TK, Alzubaidi AS, Mohamed Elbaz A. Beyond reality: harnessing the metaverse for transformative education through UTAUT-2 and task-technology synergy. Int J Manag Educ. 2025;23(2):101169.

11. Li Q, Duan H, Zhou X, Sun X, Tao L, Lu X. The use of metaverse in medical education: a systematic review. Clin Med (Lond). 2025;25(3):100315.

12. Miri B, David BC, Uri Z. Purposely teaching for the promotion of higher-order thinking skills: a case of critical thinking. Res Sci Educ. 2007;37(4):353–69.

13. Akyürek S, Genç G, Çalık İ, Şengel Ü. Metaverse in tourism education: a mixed method on vision, challenges and extended technology acceptance model. J Hosp Leis Sport Tour Educ. 2024;35:100503.

14. Jans C, Levett-Jones T, Lucas C. Utilisation, application and effectiveness of metaverse in simulation-based nursing education: protocol for a mixed methods systematic review. Clin Simul Nurs. 2024;97:101626.

15. Nguyen AHD, Le TT, Dang TQ, Nguyen LT. Understanding metaverse adoption in education: the extended UTAUMT model. Heliyon. 2024;10(19):e38741.

16. Li W, Huang JY, Liu CY, Tseng JCR, Wang SP. A study on the relationship between students' learning engagements and higher-order thinking skills in programming learning. Think Skills Creat. 2023;49:[article].

17. Antonio RP, Prudente MS. Effects of inquiry-based approaches on students' higher-order thinking skills in science: a meta-analysis. Int J Educ Math Sci Technol. 2023;12(1):251–81.

18. Islami S, Ambiyar A, Sukardi S, Candra O, Wulansari RE, Agni Zaus M, et al. The role of artificial intelligence in flipped interactive learning: building a generation of critical thinkers, skilled communicators, effective collaborators, and creative innovators. Salud Ciencia Tecnol. 2024;4:[article].

19. Zaus MA, Eliza F, Andriani C, Candra O, Jalil SA, Zaus AA, et al. Leveraging algorithm instruction with AI chatbots: a detailed exploration of their impact on students' computational thinking. Int J Inf Educ Technol. 2025;15(5):891–901.

20. Sukardi, Candra O, Mirshad E, Zaus MA, Islami S. Leveraging smart home training kits as an innovative educational tool to foster higher-order thinking skills. Data Metadata. 2025;4:476.

21. Xu X, Tong W, Wei Z, Xia M, Lee LH, Qu H. Transforming cinematography lighting education in the metaverse. Vis Inform. 2025;9(1):1–17.

22. Maghaydah S, Al-Emran M, Maheshwari P, Al-Sharafi MA. Factors affecting metaverse adoption in education: a systematic review, adoption framework, and future research agenda. Heliyon. 2024;10(7):e28602.

23. Al-kfairy M, Ahmed S, Khalil A. Factors impacting users' willingness to adopt and utilize the metaverse in education: a systematic review. Comput Hum Behav Rep. 2024;15:100459.

24. Malann D, Al-Turjman F. Metaverse technology in education: an enhancement for the future. In: Artificial Intelligence of Things (AIoT). Elsevier; 2025. p. 23–36.

25. Wang W, Wang Y, Hu Y, Zhang T, Wu Q. Assessment of metaverse integration options in the higher education institution using interval-valued T-spherical fuzzy–WHMA–CEM–GLDS framework. Appl Soft Comput. 2024;156:111514.

26. Zhang G, Ali J, Kim DW, Kim S, Kim J. Why people use metaverse education for learning. Int J Technol Hum Interact. 2025;21(1):1–23.

27. Jalinus N, Ganefri, Zaus MA, Wulansari RE, Nabawi RA, Hidayat H. Hybrid and collaborative networks approach: online learning integrated project and Kolb learning style in mechanical engineering courses. Int J Online Biomed Eng. 2022;18(15):4–16.

28. Saifi AG, Khlaif ZN, Affouneh S. The effect of using community-based learning program in science students' achievement according to Kolb's learning styles. Soc Sci Humanit Open. 2024;10:101125.

29. Fani T, Ghaemi F. Implications of Vygotsky's zone of proximal development (ZPD) in teacher education: ZPTD and self-scaffolding. Procedia Soc Behav Sci. 2011;29:1549–54.

30. Donkor A, Boakye E, Atuanor P, Wiafe YA. Evaluation of a classroom-based medical imaging artificial intelligence educational intervention in Ghana: a pre-test/post-test study design. Radiography. 2025;31(4):102987.

31. Vetter MA, Lucia B, Jiang J, Othman M. Towards a framework for local interrogation of AI ethics: a case study on text generators, academic integrity, and composing with ChatGPT. Comput Compos. 2024;71:102831.

32. Markula A, Aksela M. The key characteristics of project-based learning: how teachers implement projects in K-12 science education. Discip Interdiscip Sci Educ Res. 2022;4(1):2.

33. Marnewick C. Student experiences of project-based learning in agile project management education. Proj Leadersh Soc. 2023;4:100096.

34. Quint J, Condliffe B. Project-based learning: a promising approach to improving student outcomes. MDRC Publications. 2018;(January).

35. Alves AC, Mesquita D, Moreira F, Fernandes S. Teamwork in project-based learning: engineering students' perceptions of strengths and weaknesses. In: Int Symp Project Approaches Eng Educ. 2011. p. 23–32.

36. Ashraf MH, Özpolat K, Yalcin MG, Shah P. A project-based learning approach to supply chain mapping education. Int J Manag Educ. 2025;23(2):101128.

37. Abdurrahman IS, Mahmudah FN. Development of a digital-preneurship measurement instrument: alignment approach through project-based learning. Int J Educ Method. 2023;9(1):283–95.

38. Kaldi S, Filippatou D, Govaris C. Project-based learning in primary schools: effects on pupils' learning and attitudes. Educ 3-13. 2011;39(1):35–47.

39. Susantini E, Isnawati, Raharjo. HOTS-Link mobile learning application: enabling biology pre-service teachers to devise HOTS-based lesson plans. J Sci Educ Technol. 2022;31(6):783–94.

40. Wayan Widana I. The effect of digital literacy on the ability of teachers to develop HOTS-based assessment. In: J Phys Conf Ser. Institute of Physics Publishing; 2020.

41. Barbosa MTJ, Carvalho MM. Enhancing sensing capabilities in project-based organizations: the role of knowledge transfer between commercial and operational teams. Int J Proj Manag. 2025;43(5):102724.

42. Sukardi S, Jalinus N, Islami S, Sakti RH, Husnuzhan H, Zaus AA, et al. Soft skills and hard skills needed in Industry 4.0 for electrical engineering students. J Appl Eng Technol Sci. 2023;5(1):142–9.

43. Kong SC, Hu W. A study of developing administrative staff's conceptual understanding of generative artificial intelligence through professional development: evaluation of a course using tests, surveys and thematic analysis of reflective writings. Comput Educ Artif Intell. 2025;9:100444.

44. Riar M, Morschheuser B, Zarnekow R, Hamari J. Gamification of cooperation: a framework, literature review and future research agenda. Int J Inf Manag. 2022;67:102549.

45. Wulansari RE, Fortuna A, Marta R, Primawati P, Masek A, Kaya D, et al. Revolutionizing learning: unleashing the power of technology gamification-augmented reality in vocational education. TEM J. 2024;[online ahead of print]:2384–97.

46. Sakti RH, Jalinus N, Sukardi, Hidayat H, Wulansari RE, Tin CT, et al. Diving into the future: unravelling the impact of Flowgorithm and Discord fusion on algorithm and programming courses and fostering computational

thinking. Int J Learn Teach Educ Res. 2024;23(7):347-67.

47. Primawati, Wulansari RE, Primandari SRP, Erizon N, Mulyanti, Purwantono, et al. Comparing the effects of flipped classroom approach with YouTube videos and conventional method on student learning in calculus: a quasi-experimental study in mechanical engineering. 2024. p. 020013.

48. Islami S, Agni Zaus M, Agni Zaus A. Development of an online project-based learning assessment instrument for vocational education students. JKIP J Kajian Ilmu Pendidik. 2024;4:[article].

49. Jalinus N, Rizal F, Wulansari RE, Zaus MA, Islami S. Design and need analysis of computer devices' expert system using forward chaining method. Int J GEOMATE. 2019;17(61):202-7.

50. Zaus MA, Syah N, Jalinus N, Ema Wulansari R, Islami S. Development instructional media on static and dynamic electrical based on Android as student-center learning media. Int J Sci Technol Res. 2019;8(11):[article].

FINANCING
The authors would like to thank Lembaga Penelitian dan Pengabdian Masyarakat Universitas Negeri Padang for funding this work with a contract number: 2090/UN35.15/LT/2025.

CONFLICT OF INTEREST
The authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION
Conceptualization: Sukardi, Mahesi Agni Zaus, Bulkia Rahim, Syaiful Islami, Yee Mei Heong.
Data curation: Sukardi, Oriza Candra, Mahesi Agni Zaus.
Formal analysis: Mahesi Agni Zaus, Bulkia Rahim, Syaiful Islami, Yee Mei Heong.
Research: Sukardi, Oriza Candra, Mahesi Agni Zaus, Syaiful Islami.
Methodology: Sukardi.
Project management: Sukardi, Mahesi Agni Zaus, Syaiful Islami.
Resources: Sukardi, Oriza Candra, Mahesi Agni Zaus.
Software: Bulkia Rahim, Syaiful Islami.
Validation: Sukardi, Oriza Candra.
Display: Syaiful Islami.
Drafting - original draft: Mahesi Agni Zaus, Syaiful Islami.
Writing - proofreading and editing: Sukardi, Oriza Candra, Mahesi Agni Zaus, Bulkia Rahim, Syaiful Islami, Yee Mei Heong.