



IMPROVING OCCUPATIONAL HEALTH AND SAFETY (K3) UNDERSTANDING THROUGH VR AND METAVERSE BASED IMMERSIVE LEARNING

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Abstract

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Low understanding of Occupational Health and Safety (K3) among Vocational High School (SMK) students is often caused by limited practical facilities and the dominance of conventional teaching methods that fail to create contextual learning experiences. To address this gap, this study aims to develop and test the feasibility, practicality, and effectiveness of Virtual Reality (VR) and Metaverse-based educational media in improving students' K3 understanding. This study uses the Research and Development (R&D) method with the ADDIE model. The implementation and evaluation stages involved a Quasi-Experiment (Nonequivalent Control-Group Design) with 32 student subjects, divided into an Experimental Class (VR/Metaverse) and a Control Class (conventional). Feasibility and practicality were measured through response questionnaires (Likert scale), while effectiveness was analyzed using N-Gain and T-Tests (Independent and Paired Samples). The product was proven to be conceptually Feasible (validation score 3.62) and Empirically Very Practical (mean teacher score 3.91 and student score 3.48). Effectiveness test results showed the Experimental Class achieved a mean N-Gain of 0.67 (Moderately Effective category), far exceeding the Control Class (0.39). Independent T-Test ($p=0.003$) and Paired T-Test ($p=0.000$) consistently proved a significant improvement in K3 understanding in the VR and Metaverse media user group. VR and Metaverse-based educational media are effective and statistically significant in improving students' K3 understanding, while providing an innovative immersive learning solution that overcomes the limitations of practical infrastructure in vocational education environments.

Keywords: Virtual Reality; Metaverse; Occupational Health and Safety; K3, Immersive Learning

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INTRODUCTION

Education serves as the primary foundation for shaping individual character and capabilities to face contemporary challenges. To prepare a skilled workforce, the government, through the Ministry of National Education, has developed Vocational High Schools (SMK) as institutions aimed at producing intermediate-level skilled labor. In accordance with Government Regulation No. 19 of 2005 on National Education Standards, SMK graduates are expected not only to master technical competencies but also to possess a deep understanding of Occupational Health and Safety (K3) as a fundamental element of safe and professional work behavior (Gultom et al., 2021).

The significance of K3 is increasingly evident from concerning global data. The International Labour Organization (ILO) estimates over 2.78 million work-related deaths annually, with an additional approximately 374 million non-fatal occupational accidents (ILO, 2022). Data from BPJS Ketenagakerjaan shows an alarming increase in work accident cases in Indonesia year by year. Recorded cases reached 234,270 in 2022, up from 221,740 cases reported in 2021 (BPJS Ketenagakerjaan, 2023). This increase indicates that understanding and implementation of K3 procedures still need significant improvement, not only in industrial environments but also early on in educational institutions such as SMKs. Weak foundational understanding of K3 among prospective workers during their education contributes to poor safety culture when they enter the workforce (Menggo et al., 2022)

In the SMK environment, particularly in technical study programs, students face various potential work hazards during practical activities. However, their literacy in K3 is often inadequate. The root problem lies in two main factors: first, the lack of innovative and engaging learning media, and second, the limitations of adequate practical facilities and infrastructure in school workshops. Consequently, K3 learning approaches still frequently rely on conventional methods like lectures and static teaching materials (textbooks or posters), which are considered less effective in creating risk situation simulations and building deep K3 awareness among students (Pambudi & Harjanto, 2020). This traditional approach fails to provide the contextual experience needed to translate theory into automatic safe behavior in work environments.

Another inhibiting factor is students' lack of learning motivation. Without engaging learning experiences or seeing the direct relevance of K3 materials, students tend to be passive and struggle to master them. This aligns with Self-Determination Theory, which posits that intrinsic motivation wanes when learning environments fail to foster autonomy and competence Ryan & Deci (2020). According to Pecson & Sarmiento, (2024), the lack of interactive learning media and simulations makes it difficult for students to imagine the importance and application of K3 in real work situations, consequently reducing their intrinsic motivation. This is because humans learn more effectively when abstract information is presented as words and integrated visuals, aiding the construction of mental models a principle central to multimedia learning (Mayer, 2020). This creates a cycle where limited facilities lead to didactic learning methods, which are less effective for knowledge retention and skill development (Lampropoulos et al., 2022) ultimately diminishing students' desire and understanding of K3. Research in vocational education confirms that immersive technologies break this cycle by providing realistic, contextualized practice that boosts engagement and perceived relevance (Garzón et al., 2019).

A case study conducted at SMKN 5 Batam revealed several fundamental obstacles in the K3 learning process. The main identified barrier was the limitation of practical facilities and infrastructure, particularly the inadequate availability of Personal Protective Equipment (PPE) and simulation tools for critical practices such as fire handling (fire extinguishers) and working at heights. This condition directly impacts students' understanding quality, as they struggle to internalize materials due to the theoretical nature of K3 learning in classrooms with minimal practice. This lecture-dominated approach makes the material abstract and disconnected from real experience (Saleh et al., 2023)

Addressing these challenges, one innovative effort that can be implemented is adopting Virtual Reality (VR) based learning methods as a transformative solution. This technology not only serves as an alternative to conventional teaching aids but can create immersive and risk-free learning environments for students. Through VR simulations,

students can directly experience various hazardous work scenarios, such as fire handling using extinguishers, working at height procedures, or proper PPE usage protocols, without facing dangerous physical consequences (Zhao et al., 2020).

Responding to these challenges, this research focuses on developing and implementing immersive learning technology based on VR and Metaverse as an innovative solution. This technology enables realistic work environment simulations, allowing students to practice safety procedures and understand risk impacts without facing actual dangers. Previous research (McLellan, 1994; Youngblut, 1998) has shown that VR effectively enhances understanding through experience-based and constructivist learning.

Based on this background, this research was conducted to address K3 learning problems at SMKN 5 Batam. Preliminary case studies identified that K3 learning at the school was hindered by limitations in teaching aids, such as PPE and simulation tools, causing students difficulties in understanding and practicing the material. Lack of student motivation was also a contributing factor. Therefore, researchers are interested in developing VR and Metaverse-based educational media as substitutes for practical tools that can present interactive simulations. This media also utilizes metaverse spaces to facilitate student collaboration, making the learning process more engaging and participatory.

METHODS

This study employs the Research and Development (R&D) method, which aims to develop and evaluate the feasibility of Virtual Reality (VR) and Metaverse-based Occupational Health and Safety (K3) educational media for students of SMKN 5 Batam. The R&D approach was selected as it is suitable for creating specific products and testing their effectiveness within the context of vocational education (Branch, 2009; Richey & Klein, 2014). The development model used is ADDIE (Analysis, Design, Development, Implementation, Evaluation), which is implemented through several systematic stages.

The first stage is Analysis, where researchers identify K3 learning problems and needs through field observations, interviews, and literature studies. Subsequently, in the Design stage, product design is carried out, including the creation of storyboards, flowcharts, preparation of teaching materials, and development of assessment instruments. The Development stage involves product realization using SketchUp and Spatial.io software, which is then validated by subject matter and media experts to ensure content and technical feasibility. After revisions based on expert feedback, the product is tested in three stages. Expert Validation assesses the conceptual feasibility of the product, followed by Individual Trials with 3 students to obtain initial feedback. The final stage is a Field Trial involving 32 students divided into an experimental group (using VR/Metaverse media) and a control group (conventional learning), using a Quasi-Experimental design of the Nonequivalent Control-Group Design type. Students' K3 understanding is measured through pre-test and post-test.

Data were collected through observation, interviews, questionnaires, and tests. Data analysis uses descriptive statistics with a 4-point Likert scale to assess feasibility and practicality, where a minimum average score of 2.50 is categorized as feasible. To measure effectiveness, N-Gain analysis and T-Tests (Independent Samples T-test and Paired Sample T-test) were used, preceded by prerequisite tests for normality and homogeneity.

RESULTS & DISCUSSION

Results

This study employs the ADDIE development model (Analysis, Design, Development) to produce a feasible, practical, and effective VR and Metaverse-based Educational Media for enhancing K3 understanding among students at SMKN 5 Batam. The initial development stages comprising Needs Analysis, Conceptual Design, and Prototype Development (including expert validation) have identified the necessity for immersive media to deliver K3 simulations and have yielded a product that meets conceptual feasibility standards (significant at $p=0.000$). Subsequent product testing results are categorized into two main aspects: Empirical Feasibility (Practicality), measured through teacher and student feedback, and Product Effectiveness, evaluated via N-Gain analysis and T-Tests on improvements in student learning outcomes.

Initial Product Development (Analysis, Design, and Development)

The development of Virtual Reality (VR) and Metaverse-based K3 Educational Media has successfully completed the first three stages of the ADDIE model: Analysis, Design, and Development.

Analysis Phase

The analysis phase identified an urgent need for interactive learning media. Students at SMKN 5 Batam faced difficulties understanding K3 procedures and the functions of supporting tools, while teachers primarily relied on conventional teaching methods. These findings highlighted the necessity of simulation technology to bridge the gap between theory and practice, particularly for high-risk K3 topics.

Design Phase

Based on the analysis findings, the design phase involved aligning content with Basic Competencies (KD), creating learning flowcharts, developing storyboards, and gathering 3D object assets. The learning flow was designed to provide an immersive experience for students, ensuring logical progression from theory to practical application.

Development Phase

The final product development utilizes two main technological platforms: SketchUp for 3D object prototype modeling and Spatial.io as the metaverse environment infrastructure. The created virtual space is organized into three specialized functional zones designed to support immersive and interactive learning. The K3 Equipment Prototype Zone enables students to conduct detailed exploration of various safety equipment through interactive 3D models. The Demonstration Zone presents K3 procedure simulations in various specific work scenarios that simulate real conditions. Meanwhile, the VR Training Zone functions as an applied practice space where learners can apply acquired knowledge through direct simulations using VR devices. These three zones are integrated within one cohesive metaverse environment, creating a progressive learning flow from concept introduction to practical application.

This zonal structure facilitates a systematic and in-depth learning journey, guiding students from introductory concepts to virtual implementation of K3 procedures. The development phase underscores the product's alignment with modern pedagogical principles, leveraging immersive technology to address gaps in traditional K3 training methods.

Expert Validation

The development phase continued with a validation process conducted by subject matter and media experts.

Table 1.
 Expert Validation Results

Validator	Average Score	Feasibility Category	Main Recommendations	Improvement
Subject Matter Expert	3.67	Feasible	Addition of interactive content (quizzes/games), provision of pre-test and post-test links, and enhancement of the PPE usage demonstration area.	
Media Expert	3.57	Feasible	Improvement of 3D object layout, addition of descriptive labels for each tool, and refinement of the teacher avatar's appearance to be more formal.	
Overall Average	3.62	Feasible	–	

Source: Data Processed by the Researcher (2025)

Overall, the validation results indicate that the VR and Metaverse-based K3 educational media has met the feasibility criteria in terms of content and media, with a final average score of 3.62. Based on this assessment, the media is deemed suitable for limited field testing after revisions based on the experts' suggestions. This success demonstrates that the developed product is not only responsive to the learning needs at SMKN 5 Batam but also possesses a solid design and content foundation to support more effective and engaging K3 teaching and learning processes.

Media Practicality Test

The practicality testing of the Virtual Reality (VR) and Metaverse-based educational media was conducted in two stages: a One-to-One Trial and a Field Trial, using response questionnaires from teachers and students. The One-to-One Trial results showed that teachers' responses to the media yielded an average score of 3.91, categorized as "Highly Practical." Similarly, the responses from three students in the one-to-one trial resulted in an average score of 3.47, also falling under the "Highly Practical" category. After revisions based on initial feedback, the product was tested in a Field Trial involving 16 students. The students' responses at this stage produced an average score of 3.48, confirming the "Highly Practical" category for its use as a K3 learning medium. This practicality value is supported by high ratings in the aspects of Benefits (average 3.65–4.00) and Media Appearance (average 3.54–4.00).

Media Effectiveness Test (Improvement in K3 Understanding)

The effectiveness test was conducted through a K3 understanding assessment using a Nonequivalent Control-Group Design. This design involved two groups: an

Experimental Class using VR/Metaverse media as the treatment and a Control Class using conventional methods (presentations), with each group consisting of 16 students. The analysis results indicated a significant increase in the average scores of both groups after the treatment. However, a clear disparity in improvement was observed between the experimental and control groups, as shown in Table 2 below.

Table 2.
 Comparison of Pre-test and Post-test Scores

Class	N	Pre-test Average	Post-test Average	Increase (Δ)
Control	16	70.9	80.3	+9.4
Experimental	16	67.8	90.0	+22.2

Source: Data Processed by the Researcher (2025)

Based on the data obtained, a significant difference in the improvement of K3 understanding was observed between the experimental and control groups. The Experimental Class, which used VR/Metaverse media, showed an average increase of 22.2 points (from 67.8 to 90.0), while the Control Class, which used conventional methods, only experienced an increase of 9.4 points (from 70.9 to 80.3).

N-Gain Analysis

Normalized Gain (N-Gain) analysis was used to measure the level of understanding improvement.

Table 3.
 Table of N-Gain Calculation Results

Class	N-Gain Average	Percentage	Effectiveness Category
Control	0.39	39%	Less Effective
Experimental	0.67	67%	Moderately Effective

Source: Data Processed by the Researcher (2025)

The N-Gain analysis confirmed these findings, with the Experimental Class achieving an average of 0.67 (67%), categorized as Moderately Effective, while the Control Class only reached 0.39 (39%), categorized as Less Effective.

Hypothesis Testing (T-Test)

The statistical analysis to test the effectiveness of the VR and Metaverse media began with prerequisite tests, including Normality and Homogeneity Tests. The Normality Test using Shapiro-Wilk on IBM SPSS Statistics 23 showed that all data, both in the Control and Experimental Classes (Pre-test and Post-test), were normally distributed with significance values >0.05 (highest 0.26, lowest 0.09). Furthermore, the Homogeneity Test using Levene's Test proved that the data variances were homogeneous, as indicated by the Pre-test significance value (0.69) and Post-test significance value

(0.80), both >0.05 . With these prerequisites met, the analysis proceeded to hypothesis testing using the T-Test. The hypothesis testing was conducted through two approaches:

1. Independent T-Test: Used to compare Post-test results between classes. The results showed a significance value of 0.003 (<0.05). This finding led to the rejection of H_0 and acceptance of H_a , concluding that there is a significant difference in K3 understanding between students who used VR/Metaverse media (Experimental Class) and those who used conventional methods (Control Class).
2. Paired T-Test: Used to measure the impact of the treatment within the Experimental Class. The results yielded a significance value of 0.000 (<0.05), which also rejected H_0 and accepted H_a . This proves that there was a significant improvement in K3 understanding among students in the Experimental Class after participating in learning using VR/Metaverse-based educational media.

The consistency of these statistical findings firmly justifies the effectiveness of using VR and Metaverse media as an innovative learning tool. This media demonstrates superior potential in enhancing students' K3 understanding, surpassing the outcomes achieved by conventional learning methods.

Discussion

The findings of this study align with the global urgency regarding the integration of Occupational Safety and Health (K3) education into vocational curricula, as emphasized by UNESCO (2021) within the framework of Education for Sustainable Development. The research reinforces evidence from the International Labour Organization (2022) stating that the internalization of K3 culture from the educational stage significantly enhances graduate workforce readiness and reduces workplace accident rates. This study also supports the findings of Zhao et al., (2020), which demonstrate the effectiveness of immersive approaches in building sustainable occupational safety competencies.

This research presents an innovative breakthrough through the development of Virtual Reality (VR) and Metaverse-based educational media, consistent with World Economic Forum (2023) recommendations regarding the utilization of immersive technologies for vocational education in the industry 4.0 era (Elhussein et al., 2020). This media not only addresses the limitations of K3 practical infrastructure but also aligns with Liao et al., (2025) findings proving that VR simulations can effectively develop muscle memory and automatic responses to workplace emergencies. The implementation of this media is expected to catalyze the strengthening of safety culture while enhancing the effectiveness of K3 learning in vocational schools, as recommended by the European Agency for Safety and Health at Work (2021) within its technology-based safety education framework (Demikhov et al., 2023)

Conceptual Feasibility and Product Practicality

The developed VR and Metaverse educational media product has proven to meet high feasibility and practicality criteria based on comprehensive assessment. Conceptual feasibility validation by subject matter and media experts confirms that this product successfully presents K3 material systematically through multimodal integration (audiovisual, text, and interactive simulations) consistent with modern instructional design principles. These findings align with Mayer (2020) research in the Cambridge Handbook of Multimedia Learning, which affirms that combining visual and verbal elements in immersive environments significantly enhances conceptual understanding.

In terms of practicality, empirical testing results show highly positive user responses. Teachers rated the product as Very Practical (average score 3.91), while students in field testing gave a Very Practical rating (average score 3.48). This high acceptance level is consistent with Tovar et al., (2020) findings in *Computers & Education*, reporting that AR/VR-based learning significantly increases student engagement and perceived usefulness compared to conventional methods.

The functional superiority of this product lies in its ability to create contextual learning through interactive simulations, as emphasized by Wu et al., (2025) which found that VR training can improve procedural memory retention by up to 75% through experiential repetition. The accessibility flexibility enabling self-directed learning also supports Chenais & Görden, (2024) findings in the *British Journal of Educational Technology* regarding the effectiveness of metaverse environments for self-directed learning.

The media's practicality stems from its integrated technological advantages, particularly its ability to create near-realistic learning experiences. In controlled virtual environments, students can conduct trial and error while understanding the consequences of K3 actions without physical risk. This advantage is crucial for developing muscle memory and automatic emergency response capabilities competencies difficult to achieve through conventional lecture methods (Suh & Ahn, 2022).

Furthermore, the integration of VR and Metaverse media effectively addresses challenges related to physical resource limitations and the high costs of K3 teaching aids in vocational schools. With a single set of devices, various simulations can be repeatedly accessed. This efficiency aspect is supported by Makransky & Petersen, (2021) demonstrating that VR-based training can improve memory retention by 30-40% while reducing training time. Additionally, developing simulations in Metaverse spaces enhances collaboration and experiential learning through student interactions and cooperation in solving K3 challenges, significantly increasing motivation and understanding retention (Halamish & Elias, 2022).

The practical implications of these findings reinforce UNESCO's (2022) recommendations regarding the use of immersive technologies for vocational education, particularly in safety competency training requiring practical experience without risk (Stone, 2023).

Effectiveness in Enhancing K3 Understanding

Quantitative analysis results provide strong empirical evidence regarding the effectiveness of VR and Metaverse-based educational media in improving vocational students' K3 understanding. Findings showing significant differences between Experimental and Control Classes align with Ortiz-Barrios et al., (2022) research in *Safety Science*, reporting that VR-based training yields 30-40% higher safety understanding improvement compared to conventional methods.

The Experimental Class's N-Gain score of 0.67 indicates moderately good effectiveness, consistent with Scorgie et al., (2024) findings in *Computers & Education* stating that immersive learning environments can create deep learning experiences. This proves that VR/Metaverse media successfully transforms abstract K3 material into concrete, easily understandable experiences for students.

The significant results from the statistical analysis (Independent T-Test: $p=0.003$; Paired T-Test: $p=0.000$) provide strong empirical support for existing research on immersive technologies. These findings align with Poupard et al., (2025) whose meta-analysis in *Educational Research Review* demonstrated that immersive learning environments significantly enhance both knowledge acquisition and the development of

deeper conceptual models compared to traditional methods. Furthermore, these results corroborate the comprehensive synthesis by Muzata et al., (2024) on immersive learning in engineering education, which emphasizes that the transformative potential of VR lies precisely in its ability to create near authentic simulations that foster both conceptual understanding and practical competence - mechanisms clearly demonstrated in the current intervention.

These research findings align consistently with established literature on technology-enhanced learning. The positive impact of interactive multimedia on student learning outcomes, as demonstrated by Aprianty & Astuti (2024) provides foundational support for the current study's results. This correlation is further reinforced by complementary research from Rahayu et al., (2022) and Setyowati et al., (2020) which collectively affirm the efficacy of multimedia tools in enhancing student comprehension across various educational contexts.

Strategic recommendations derived from these findings include the need to develop systematic frameworks for integrating immersive technologies into vocational curricula, as proposed by Chenais & Gorgen, (2024) in the *British Journal of Educational Technology*. Structured implementation is expected to optimize technology's potential in forming technical competencies and safety awareness as crucial foundations for vocational graduates' workforce readiness in the digital era.

CONCLUSION

It can be concluded that the developed Virtual Reality (VR) and Metaverse-based educational media demonstrates high conceptual feasibility and empirical practicality for implementation in Occupational Safety and Health (K3) learning in vocational schools. Fundamentally, the media's effectiveness in enhancing students' K3 understanding is statistically confirmed, marked by significant learning outcome improvements in the experimental group compared to the control group. This success is supported by immersive technology's capability to facilitate contextual learning approaching real conditions (near-realistic experience), effectively overcoming conventional practical resource limitations while fostering sustainable safety awareness. Therefore, this media not only presents an innovative solution for current K3 learning challenges but also serves as a strategic foundation for sustainable vocational education development, with prospects for expanding material coverage to other vocational fields and integrating adaptive feedback technologies.

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