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Developing a Mixed Reality-based 3D Virtual laboratory for Multimedia Practicum: A Metaverse Approach

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Abstract

Background of study: Although learning media have experienced growth and variation, the trend of implementing online learning that is in accordance with the needs of the times has not fully answered the needs of students in learning independently. Specific needs especially in skill-based fields such as multimedia, electronics, automotive, and health. The transition to online practicums has been problematic due to limited access to digital versions of tools and materials, as well as restrictions on the use of physical laboratories during the pandemic.

Aims and scope of paper: This study focuses on the development of a contextually relevant educational technology solution: a 3D virtual laboratory that uses mixed reality to support online multimedia practicums. Mixed reality allows users to interact with realistic audio-visual elements such as sounds, colors, environmental activities, and specific objects, allowing for immersive navigation in a virtual setting. Incorporating Metaverse features further enhances interactivity in the virtual classroom.

Methods: This study adopted the Multimedia Development Life Cycle (MDLC) method.

Result: The results show that the 3D virtual laboratory meets all five usability criteria, namely, Ease of Learning (86.7%), System Performance (80.5%), Efficiency (87.1%), Ease of Finding (84.3%), and Fun (83.1%) which confirms its effectiveness as a usable and engaging learning tool.

Conclusion: With the design of a 3D virtual laboratory based on mixed reality as an innovation in online multimedia practicum media, it is expected to be a new form of innovation in packaging practicum media that is more interactive and useful for distance learning activities.

A. Introduction

Technological integration has become an essential component in enhancing educational quality, particularly through the implementation of modern information and communication technologies (ICT) in classroom activities. Nowadays, educational processes are rarely separated from the use of digital tools, especially in science subjects where complex phenomena need visualization. Hands-on experiments in subjects like physics, chemistry, and biology are often limited due to safety concerns and cost, which is where computer simulations and modeling offer significant support. Recent advancements have enabled more accurate digital representations of natural processes (Widodo et al., 2019). The COVID-19 pandemic has deeply affected education worldwide, forcing a rapid transition to online learning. Modern education must not merely focus on repeating content but should encourage students to explore ideas creatively and become problem solvers in real-world contexts (Sari & Sakdiah, 2016). However, there are challenges in implementing practicum in online learning. Practical learning, which should be done in face-to-face

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meetings in the laboratory, must finally adapt to the online system. As we all know, practicum learning itself is intended for students to test and implement what is in theory and then tested in real situations. Especially with students who take specialty study programs, such as multimedia, electrical science, automotive, health, and others. ICT serves as a powerful medium to deliver abstract concepts through interactive simulations and digital experiments, fostering deeper student understanding. As an alternative to in-person learning, remote education emerged as a practical response to health crises.

The arrival of Virtual-Reality, Augmented-Reality, and Mixed-Reality technologies is shaping a new environment where physical and virtual objects are integrated at different levels. Virtual reality (VR) exemplifies a system that harnesses the educational potential of multimedia (Petersen et al., 2022).

Due to the development of portable and embodied devices, together with highly interactive, physical-virtual connections, the customer experience landscape is evolving into new types of hybrid experiences (Flavián et al., 2019). In the general context of the COVID-19 pandemic, undergraduate students have had little choice other than to face high levels of confinement and have seen their social life curtailed, including social interaction during their learning process. Online learning has become a major tool in their daily life, drastically reducing one of the main positive outcomes of the learning process: the emotional component of learning (Checa et al., 2021).

Online platforms allow students and teachers to engage in learning processes without being physically present in classrooms, enabling greater accessibility and flexibility (Pratama et al., 2020). One significant innovation in this space is virtual reality (VR), along with augmented reality (AR) and mixed reality (MR) technologies (Zakharov et al., 2020). These immersive tools are part of nine key digital technologies shaping the future of education, which include video-based learning, gamification, big data, cloud computing, IoT, cybersecurity, immersive tech, artificial intelligence, and blockchain. Users can interact with real-world things enhanced by virtual elements including holographic overlays, contextual instructions, and interactive 3D models in mixed reality (MR) environments, which combine the digital and physical worlds (Cantarelli et al., 2025). VR-based learning has evolved from Computer Assisted Instruction (CAI) and Computer-Based Training (CBT) into immersive, engaging Smart Classroom experiences. Research conducted by Saenong et al. (2024), in their research stated that mixed reality-based applications made as innovative media in digital learning get good results where the application is declared effective to meet user needs. Through three-dimensional (3D) imaging and immersive virtual environments (iV), students are able to emotionally engage with learning content in new and meaningful ways (Chen et al., 2024). The success of national education is closely tied to the curriculum, instructional strategies, teacher quality, and the use of media that resonates positively with students (Hikmah et al., 2017). This is especially true in science learning, which often requires experimental activities to meet educational goals. The shift to online learning has posed a unique challenge for skill-based programs in Indonesia, particularly those requiring practical sessions in specialized laboratories. Due to restrictions during the pandemic, traditional offline support systems and project presentations have had to be partially converted into digital formats. To support this transition, innovations such as mixed reality are gaining traction. Mixed reality (MR) merges real-world environments with virtual elements through a blend of holographic technology and 3D modeling, allowing users to interact within simulated environments (Jayaputra et al., 2017). It is positioned along the virtuality continuum, representing the integration of real and virtual spaces through computational modeling (Rokhsaritalemi et al., 2020).

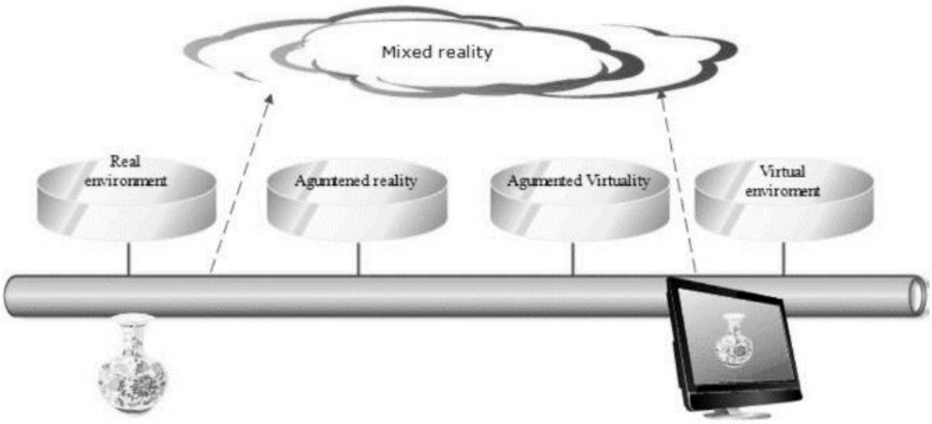


Figure 1. Mixed Reality Environtments

Learning that integrates 3D or visual technologies can enhance students' memory retention by stimulating the right brain, which helps them remember the material longer than when it's delivered through text, which mainly engages the left brain and short-term memory. With the development of virtual reality (VR) and augmented reality (AR), human interaction with computer systems has evolved, and these technologies are now widely used in applications such as education, computer-aided design, surgery, animation, and gaming. Augmented reality, which combines computer graphics with the real world, creates mixed reality and allows users to view virtual objects overlaid onto their physical environment. In education, AR is used in areas like 3D modeling, design, and architecture, and is particularly valuable in fields such as medicine, industrial training, and remote learning (Vaughan et al., 2016).

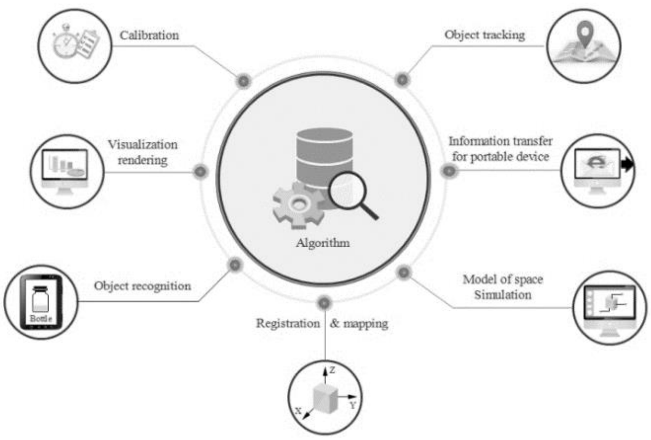


Figure 2. Mixed Reality Algorithm

Algorithms play a crucial role in mixed reality, as they are applied in various tasks such as calibrating mixed reality devices for enhanced user interaction, modeling mixed reality environments, tracking real world objects to provide relevant information, creating 3D maps, and adapting virtual models to real-world spaces. Additionally, they help create interactions between real and virtual content, enable near realistic visualization of mixed reality objects and scenarios, and optimize the output for devices like mobile phones. Mixed reality characters are typically defined by three key aspects: immersion, information, and interaction (Parveau & Adda, 2018). The development of mixed reality (MR) follows four key stages: analyzing needs, customizing components, composing components for real-time interaction, and calibrating virtual objects in real space (Guzman et al., 2019). Mixed Reality (MR) combines the characteristics of both Augmented Reality (AR) and Virtual Reality (VR), providing a distinct advantage in managing spatial information and effortlessly merging interactive holographic entities with the physical environment via spatial computing (Nakamura & Sekiyama, 2023). MR technologies, including virtual reality (VR) and augmented reality (AR), are transforming learning environments by merging physical and virtual worlds to create hybrid experiences, especially through portable devices (Flavián et al., 2019). The COVID-19 pandemic forced many students into online learning, which reduced the emotional connection that usually comes with in-person education (Checa et al., 2021). However, MR technologies, like VR and AR, are improving e-learning by immersing students in simulated environments, allowing them to interact with virtual objects and avatars, thus enhancing the learning process (Abreu & Almeida, 2018). These advancements in VR & AR are increasingly used in fields like education, healthcare, and professional development, providing immersive learning experiences that can replace traditional methods (Syahputra et al., 2020). Technological innovations, such head-mounted displays (HMDs), motion tracking systems, and sophisticated graphical designs and interaction, can affect the degree of immersion in a VR system (Kogler et al., 2021). Although these technologies have shown great potential, there is still a need to develop a comprehensive framework for practical MR applications. The Metaverse, an advanced technology providing immersive educational experiences, is transforming learning by allowing real-world users to engage and cooperate within a virtual environment (Smutny, 2023). Based on the above background, the purpose of this research is to design a 3D virtual laboratory and implement mixed reality technology into an application that can be used in online multimedia practicum learning and test the feasibility of mixed reality-based 3D virtual laboratory products, as a learning technology innovation in online multimedia practicum learning.

B. Research Methods

Mixed reality and Metaverse significantly enhance the user experience through real-time interaction and a high sense of presence. Various research results reveal that the development of mixed reality-based media is very good for the world of education because it can increase learning engagement, visualization of complex concepts, and simulation of practical work, thus becoming the basis for developing this research.

The research was conducted using the Multimedia Development Life Cycle (MDLC) methodology. The MDLC consists of six stages: Concept, Design, Material Collection, Assembly, Testing, and Distribution (Wibowo et al., 2021). These stages are flexible and may occur in any order, although the Concept phase should always be the first step. Emphasizes that the MDLC allows for a non-linear process, enabling adjustments as needed throughout the development stages (Rahayu et al., 2018; Sugiarto, 2018). The time of this research was conducted for 8 months. the place of research was conducted at UPI Cibiru campus, SMKN 14 Bandung, SMKN 11 Bandung, and SMK Daarut Tauhid Boarding School. Data collection techniques used a questionnaire instrument consists of 21 items across five dimensions of usability. Small-scale testing was carried out by multimedia education students and large-scale testing was carried out by students in three schools. The mixed reality development method and flow can be explained as follows:

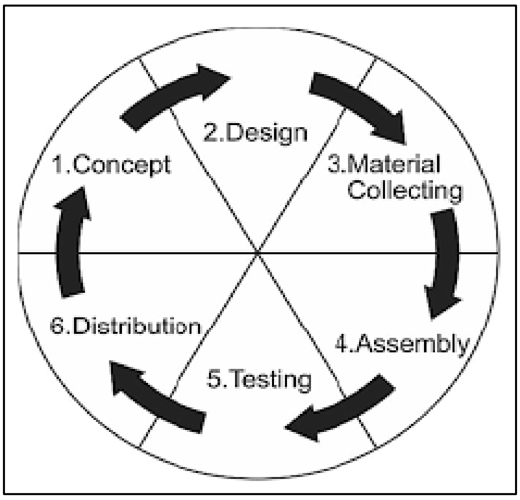
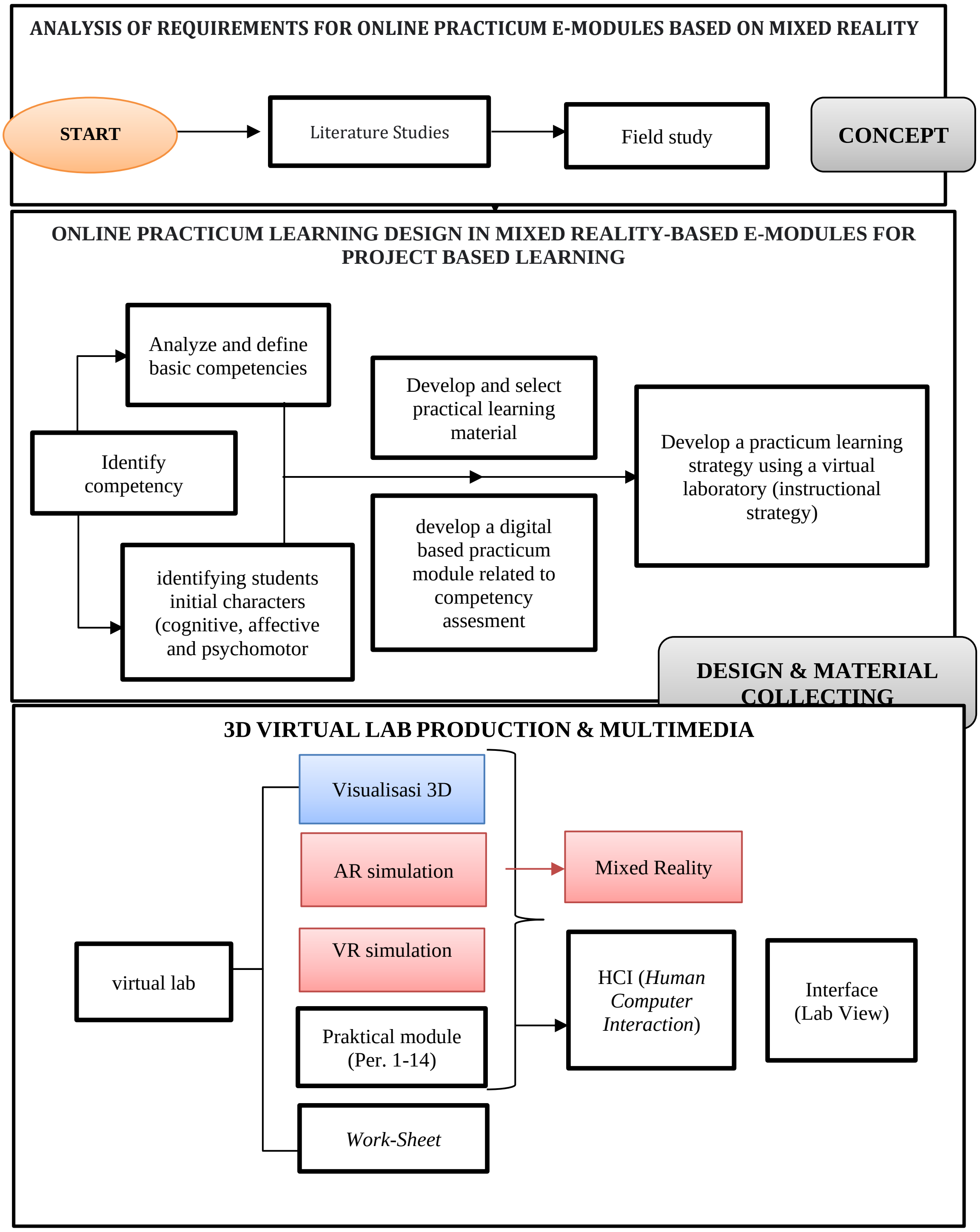


Figure 3. Multimedia Development Life Cycle (MDLC) Model


ANALYSIS OF REQUIREMENTS FOR ONLINE PRACTICUM E-MODULES BASED ON MIXED REALITY
START
Literature Studies
Field study
CONCEPT
ONLINE PRACTICUM LEARNING DESIGN IN MIXED REALITY-BASED E-MODULES FOR PROJECT BASED LEARNING
Analyze and define basic competencies
Identify competency
identifying students initial characters (cognitive, affective and psychomotor
Develop and select practical learning material
develop a digital based practicum module related to competency assesment
Develop a practicum learning strategy using a virtual laboratory (instructional strategy)
DESIGN & MATERIAL COLLECTING
3D VIRTUAL LAB PRODUCTION & MULTIMEDIA
Visualisasi 3D
AR simulation
VR simulation
Praktical module (Per. 1-14)
Work-Sheet
virtual lab
Mixed Reality
HCI (Human Computer Interaction)
Interface (Lab View)

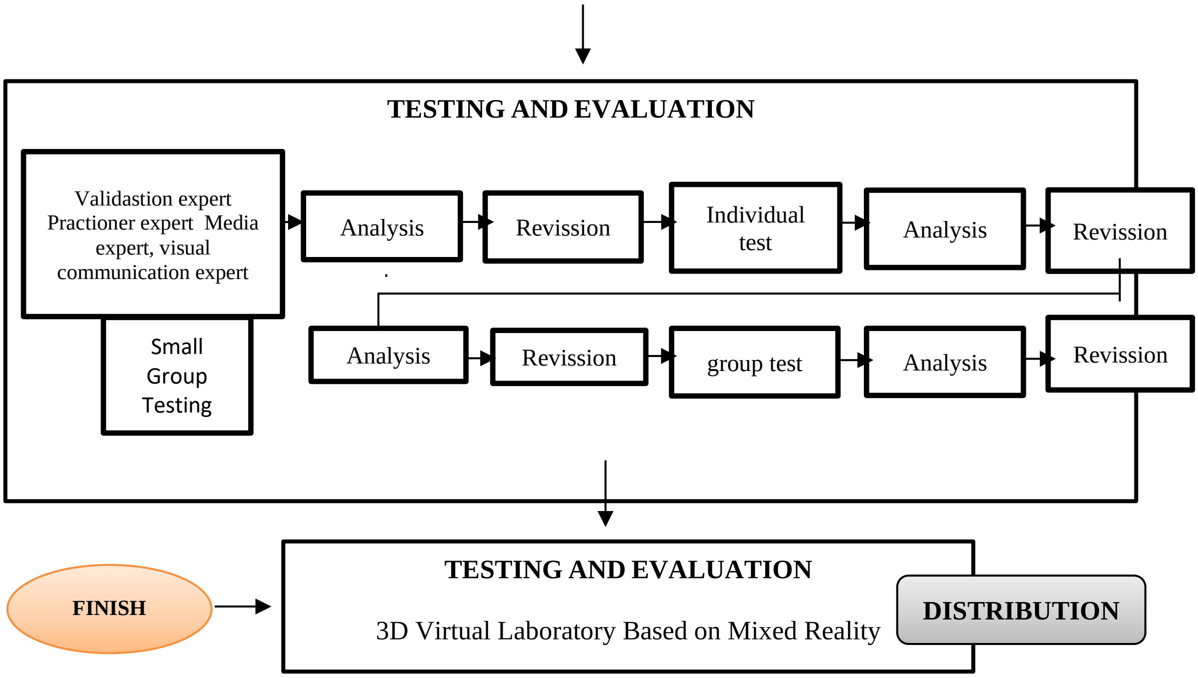


Figure 4. Research procedure of Multimedia Development Life Cycle (MDLC)

C. Results and Discussion

1. Results

Mixed reality and Metaverse significantly enhance the user experience through real-time interaction and a high sense of presence. Various research results reveal that the development of mixed reality-based media is very good for the world of education because it can increase learning engagement, visualization of complex concepts, and simulation of practical work, thus becoming the basis for developing this research.Based on the MDLC (Multimedia Development Life Cycle) research method, this section will present the discussion and results derived from the development process of the MDLC model, which includes the stages of Concept, Design, Material Collection, Assembly, Testing, and Distribution.

The laboratory taken as a research sample is a multimedia laboratory belonging to the multimedia education study program at UPI Cibiru Campus, assuming that the laboratory has fulfilled the elements to be used as a mixed reality-based laboratory, such as: Available practicum materials and tools, Available practicum modules, Well-organized laboratory space and layout.

Figure 5. Multimedia Laboratory Display 1.

1.1. Media Design and Practicum Materials in Virtual Environments

Implication in practicum learning, tools and materials play a crucial role in technical activities. In this study, the tools and materials used in the virtual laboratory will be presented in 3D visuals to help students better understand their form, function, and characteristics. Additionally, the laboratory environment will be represented in virtual reality, where the physical multimedia lab will be transformed into a three-dimensional virtual space, as illustrated below.

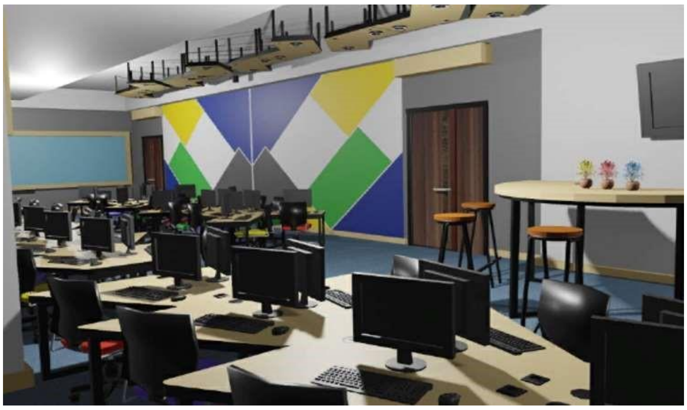


Figure 6. Multimedia laboratory in virtual form

The practicum material in the virtual environment is sourced from digital video practicum modules and then converted into augmented reality. Research contribution is develope and combining mixed reality with Augmented reality and virtual reality is a broad concept, but this study focuses on one type, namely marker-based augmented reality using QR Codes. The design and implementation of augmented reality on practicum materials with QR Codes follows four stages. First, a target image in the form of a QR Code is created manually using the website http://goqr.me. After designing the QR Code marker, practicum material assets, which have been photographed according to each session, are imported. Finally, the photos are combined with 3D objects in the virtual laboratory. During this stage, the QR Code marker is placed to correspond with each object in the virtual lab, allowing students to explore and select the practicum material they wish to engage with.

Figure 7. Illustration Of Augmented Reality Concept

1.2. Mixed Reality Based 3D Virtual Laboratory Production

In the laboratory production stage, researchers started by visualizing three-dimensional images of the laboratory space, practicum materials, and the lab's facilities and infrastructure in detail. This three-dimensional visualization serves as the foundation for virtual reality replicas, allowing users to experience an environment that closely resembles the real one. The visualization of these 3D images in multimedia laboratories can be seen as shown below:

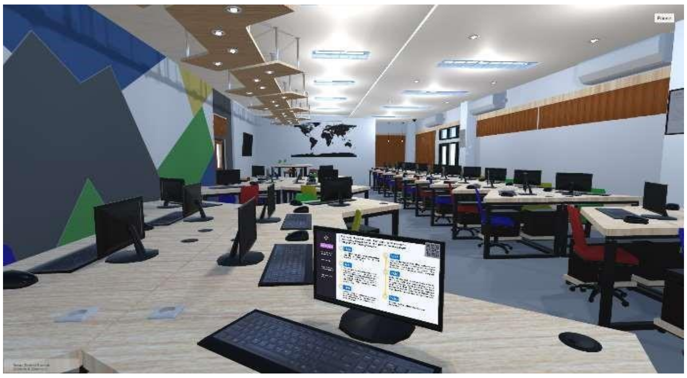


Figure 8. 3D Virtual Multimedia Laboratory

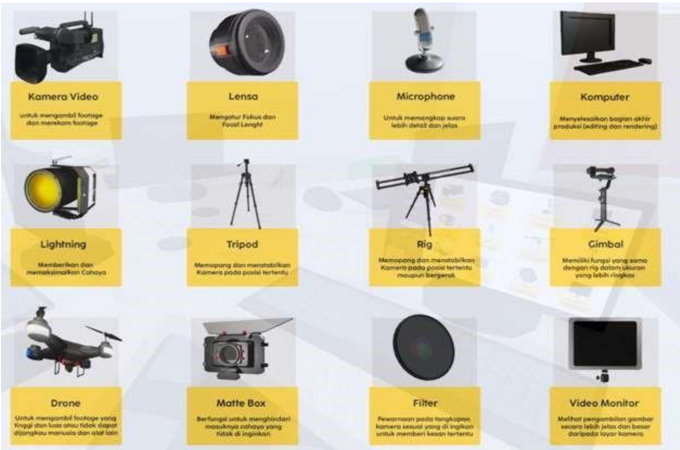


Figure 9. Practical Tools and Materials in Virtual 3D

After the 3D visualization form has been formed, the next step is to start programming augmented reality simulations and virtual reality simulations in the 3D virtual laboratory space. With the augmented reality simulation program and virtual reality simulation in one scope, it can be called a mixed reality scope. The Mixed Reality Based 3D Virtual Laboratory Program that has been built can be seen in the picture below:

Figure 10. View Of Virtual Laboratory File Extensions.

Double click on the MixRealty.exe file.

Figure 11. Virtual Laboratory User Interface Menu.

After that a Pop-Up will appear the initial display of the 3D Virtual Laboratory application.

Figure 12. Virtual Laboratory Tools and Materials Menu.

Click 1x on the “tools & materials” menu option, to see and understand what practical tools and materials are used.

Figure 13. Display of Virtual Laboratory Tools and Materials.

After that, the initial appearance of the virtual room will appear, in which there are practicum tools and materials with a 3D virtual display.

Figure 14. Display Description of Virtual Laboratory Practice Tools and Materials

Approach the object of tools and materials in the virtual space, a Pop-Up description will appear in the form of names, functions of tools and materials. Do the same for other objects of tools and materials to be explored.

Figure 15. Display of Virtual Laboratory Practicum Course Selection Menu

Click 1x on the "practicum course options" menu option, to see and understand what practicum course options are presented in the 3D virtual laboratory. After that, approach the "blackboard" object to see and select the practicum course presentation, as shown below**.**

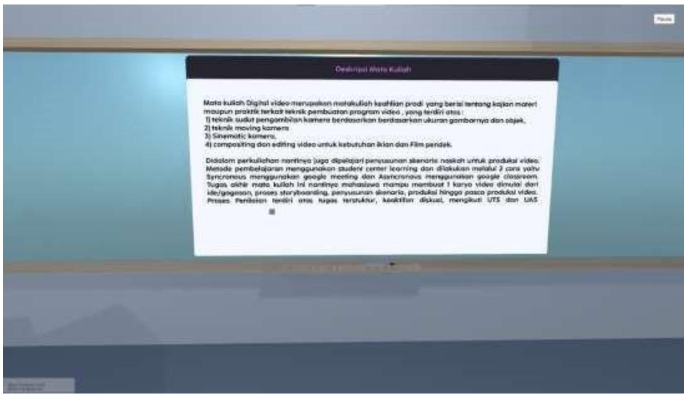


Figure 16. Virtual Laboratory Practicum Course Description Display

After selecting the practicum course, the lecture material display will appear on each "LED Monitor PC" object. Access to this lecture material can also use the "Scan QR Code" technique in the corner of the LED screen using a smartphone camera, and a Pop-Up material will appear on the smartphone screen as shown below.

Figure 17. QR Code Display of Virtual Laboratory Practicum Theory Material

Figure 18. Display of Virtual Laboratory Practicum Theory Material

Figure 19. Menu Display to Start Virtual Laboratory Practicum Simulation.

Click 1x on the “start practicum” menu option, to see and start doing practicum course activities presented in the 3D virtual laboratory.

Figure 20. Display QR Code Virtual Laboratory Practicum Simulation.

After that a pop-up “Scan QR Code” will appear on the LED screen, to start practicum using a smartphone, or if you want to use a PC or Laptop device, you can press the “Esc” key on the keyboard. The practicum start display will look like the picture below.

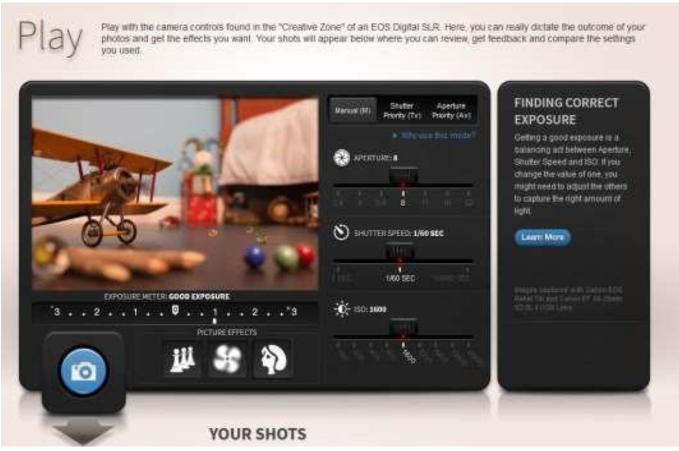


Figure 21. Virtual Laboratory Practicum Simulation Display

1.3 Testing Mixed Reality-Based 3D Virtual Laboratory

This research builds upon the findings of previous studies and progresses to the next phase, which involves testing the mixed reality-based virtual laboratory media with a group of respondents. According to ISO 9241:11, usability is defined as the extent to which a product can be used by specific users to achieve a set goal effectively, efficiently, and with satisfaction in a given context. The context of use includes users, tasks, equipment (hardware, software, and materials) (Sugiarto, 2018). Usability is measured based on the following components: a. Learnability: Refers to how quickly users can become proficient with the system and how easily they can perform desired functions. b. Efficiency: Refers to the resources required to achieve goals with accuracy and completeness. c. Memorability: Refers to the user's ability to retain knowledge after a period of time, which is supported by fixed menu placements. d. Errors and Security: Refers to the number of mistakes users make, including discrepancies between what users expect and what the system actually presents. e. Satisfaction: Refers to the freedom from discomfort and the positive attitude users have towards using the product, reflecting how users feel about the system. A small-scale test was conducted in the computer lab at the UPI Cibiru campus, involving 50 multimedia education students.

Figure 22. Virtual Laboratory Testing

After collecting the respondent's data, the next step is to compute the percentage using a Likert scale. The Likert scale typically includes four or more questions that together generate a score or value reflecting individual traits such as knowledge, attitudes, and behaviors. It is also considered a psychometric scale, commonly used in questionnaires and widely employed in research. The results of the total conclusions from the first and second stages are as follows:

Table 1. Table of total test results

Force	Learnability	System Performance	Discoverability	Efficiency	Delight	Total
2018	181	289	133	132	183	940
2020	279	448	199	210	255	1378
Maximal Score						2625

Overall percentage = $\frac{Total\ score\ obtained}{Maximum\ number\ of\ scores}$ $\frac{940+\ 1378\ x\ 100}{2625}$ = 88.3 %

Details of media testing for each usability testing indicator are described in the following table:

Table 2. Usability Testing Indicator Table

Instrument	Testing	Maximum Value	Total Percentage	Description
Learnability	460	500	92%	Successful
Sistem Performance	737	875	84%	Successful
Discoverability	332	375	88%	Successful
Eficiency	342	375	91%	Successful
Delight	438	500	87,6%	Successful

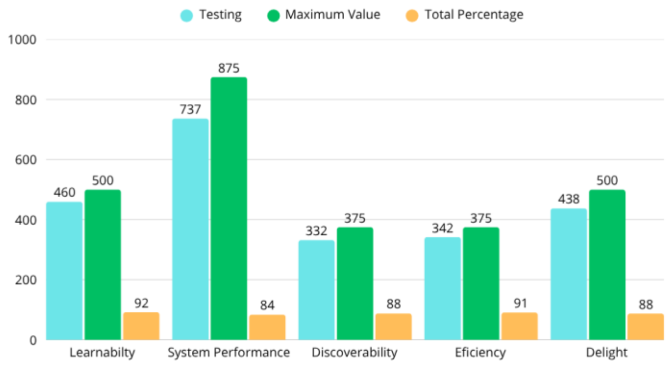


Figure 23. Bar graphs usability scores

A large-scale test will be conducted at three Vocational High Schools: SMKN 11 Bandung, SMKN 14 Bandung, and SMK Daarut Tauhid Bandung. The research participants will be chosen by the researcher who designed the product, and these selected students will be involved in testing the product's feasibility. To ensure the system's implementation aligns with the research goals, it is essential that both the quality and quantity of the data collected are high. The instruments used for data collection include literature studies on the use and development of virtual laboratory technology in education, semi-structured interview guides to gather feedback on the performance of Mixed Reality in 3D virtual laboratory environments, and surveys to collect data on the feasibility of the research product.

Figure 24. Student Responses to Learnability of Metaverse Features in 3D Virtual Laboratory Service Based on Mixed Reality as Media Innovation Practicum in Multimedia

Description: 1 = Very Poor; 2 = Poor; 3 = Fair; 4 = Good; 5 = Very Good

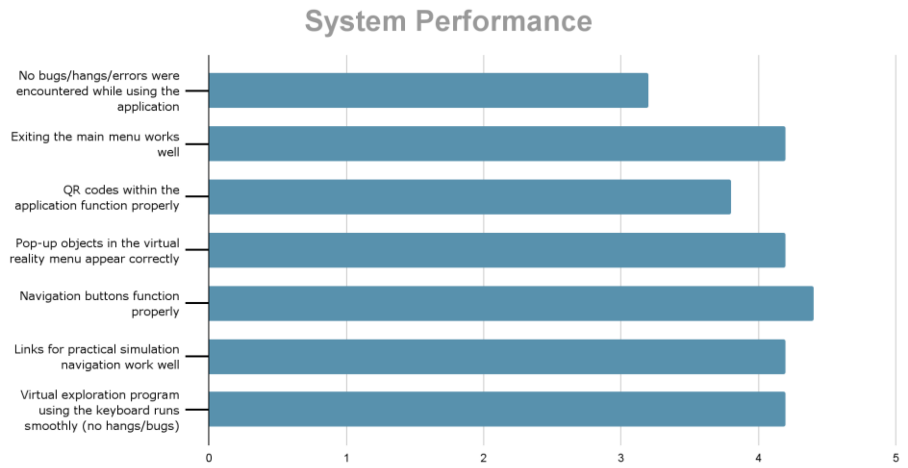


Figure 25. Student Responses to System Performance of Metaverse Features in 3D Virtual Laboratory Service Based on Mixed Reality as Media Innovation Practicum in Multimedia

Description: 1 = Very Poor; 2 = Poor; 3 = Fair; 4 = Good; 5 = Very Good

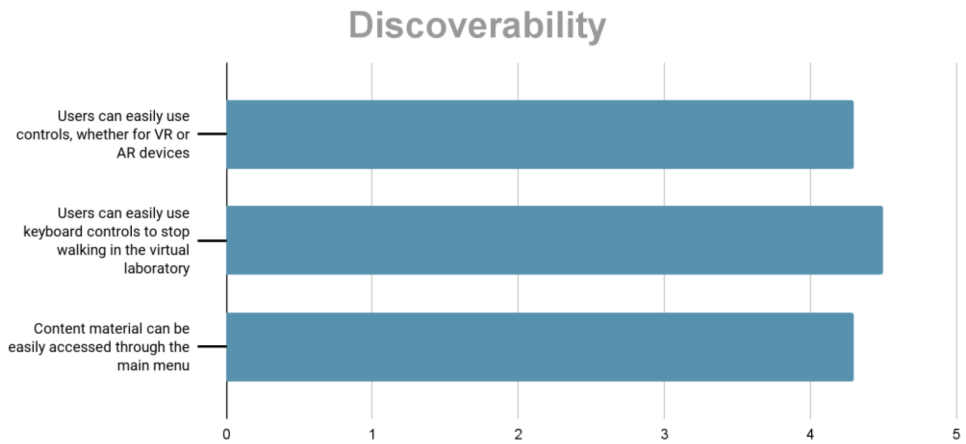


Figure 26. Student Responses to Discoverability of Metaverse Features in 3D Virtual Laboratory Service Based on Mixed Reality as Media Innovation Practicum in Multimedia

Description: 1 = Very Poor; 2 = Poor; 3 = Fair; 4 = Good; 5 = Very Good

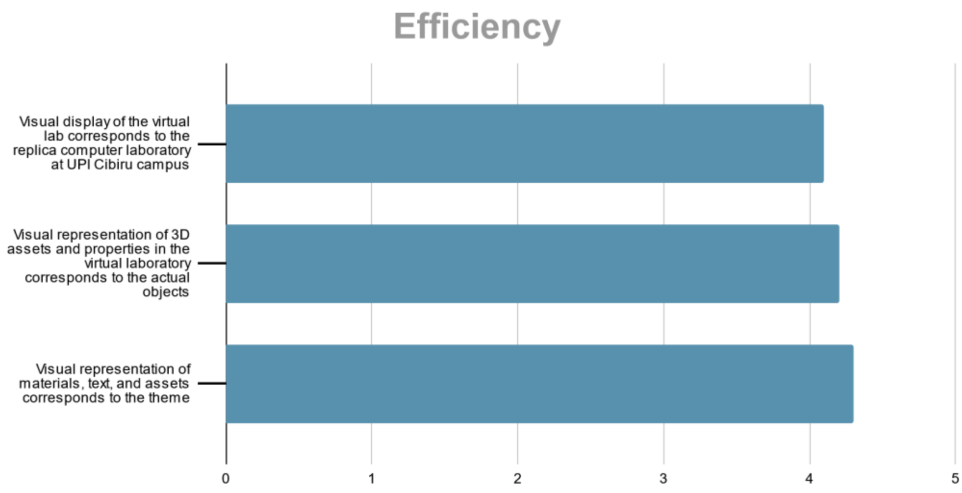


Figure 27. Student Responses to Efficiency of Metaverse Features in 3D Virtual Laboratory Service Based on Mixed Reality as Media Innovation Practicum in Multimedia

Description: 1 = Very Poor; 2 = Poor; 3 = Fair; 4 = Good; 5 = Very Good

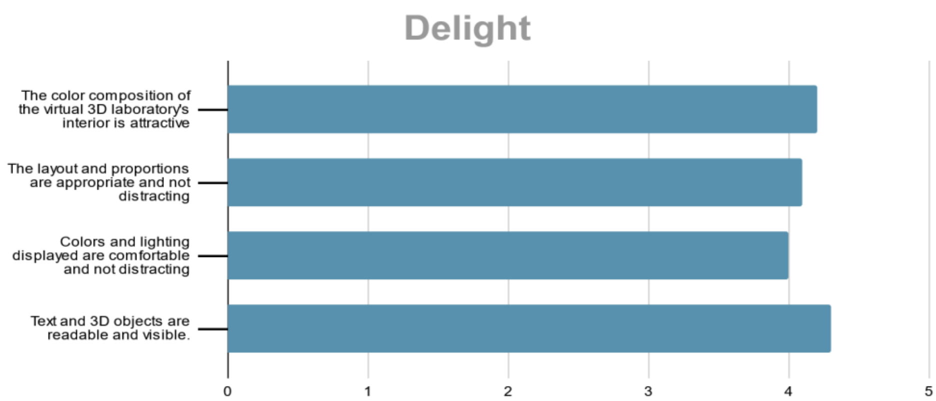


Figure 28. Student Responses to Delight of Metaverse Features in 3D Virtual Laboratory Service Based on Mixed Reality as Media Innovation Practicum in Multimedia

Description: 1 = Very Poor; 2 = Poor; 3 = Fair; 4 = Good; 5 = Very Good

The 3D virtual laboratory application satisfies all five variables, indicating that it meets the criteria for Usability, in the Learnability criteria, the results obtained are 86.7%, where these results state that the mixed reality application is easy to use. In the System Performance criteria, the results obtained are 80.5%, where these results state that the system performance of the application runs well with minimal bugs and errors, all buttons run well and the use of the keyboard to play the player has no problems. On the Efficiency criteria, the results obtained are 87.1%, where these results state that the visual or 3D model of objects in the mixed reality application is in accordance with the actual situation in the Multimedia laboratory. In the Discoverability criteria, the results obtained are 84.3%, where these results state that users can easily use the controls in the application. In the Delight criteria, the results obtained are 83.1%, where these results state that the user interface, visual, layout, text and 3D objects are in good and appropriate appearance. The documentation of the testing activities from the first stage is provided below:

Figure 29. Respondent For Testing Media.

2. Discussion

This study demonstrates that the development of a Mixed Reality (MR)-based 3D virtual laboratory offers an innovative solution to overcome the limitations of physical laboratories in multimedia practicum conducted online, particularly under the constraints imposed by the COVID-19 pandemic. The implementation of MR technology, which integrates augmented reality (AR) and virtual reality (VR), creates an immersive, interactive, and realistic learning environment that enhances student engagement and motivation (Crogman et al., 2025). Usability testing results indicate that the developed application exhibits high ease of use and stable system performance, thereby supporting the effectiveness of online practicum learning. These findings align with existing literature emphasizing the potential of immersive technologies to improve conceptual understanding and practical skills among learners (Serrano-Ausejo & Mårell-Olsson, 2024). The contribution of this research lies not only in the technological innovation presented but also in the systematic application of the Multimedia Development Life Cycle (MDLC) methodology, encompassing stages from conceptualization to evaluation and distribution. This comprehensive framework facilitates the iterative development of advanced educational media and allows for continuous refinement based on user feedback. Furthermore, involving users in both small- and large-scale testing enhances the validity of the findings by capturing real-world needs and challenges faced during the use of online practicum media. Such an approach ensures that the developed tool is not only technically advanced but also relevant and readily adoptable within vocational education settings. Nevertheless, this study has limitations that warrant consideration for future development and research. The testing sample was geographically limited to Bandung and focused solely on multimedia practicum, which restricts the generalizability of the results to broader contexts or other vocational fields. Additionally, technical aspects such as device compatibility, internet bandwidth requirements, and long-term learning impact assessments were not deeply explored. Future studies are recommended to conduct wider and more in-depth testing, including content expansion across various vocational disciplines and integration of assessment features to quantitatively measure media effectiveness. Such efforts will further enhance the MR-based virtual laboratory into a more holistic educational tool with significant impact on vocational education quality.

2.1 Implications

The development of a 3D virtual laboratory based on Mixed Reality provides an effective and interactive practicum alternative in the context of distance learning, especially during pandemic conditions or limited access to physical laboratories.

This media can increase student engagement and motivation to learn by presenting an immersive and realistic learning experience, which is difficult to obtain through conventional learning media.

The application of Mixed Reality technology and Metaverse features opens up opportunities for vocational education institutions to integrate cutting-edge technology into their curriculum, while preparing students for an increasingly digital and high-tech world of work.

This model can also be applied and developed for other practicum fields outside multimedia, such as electrical engineering, automotive, or health, thus expanding its benefits in vocational education.

2.2 Research Contribution

This article presents the design and implementation of a Mixed Reality-based practicum laboratory with Metaverse technology integration that is quite comprehensive, filling the void of literature related to interactive and realistic online practicum media.

Using the Multimedia Development Life Cycle (MDLC) method systematically as a development framework provides practical guidance for researchers and developers of similar digital learning media.

The feasibility test results involving real users (university students and vocational students) provide empirical evidence that this media is effective, easy to use, and fun, thus strengthening the argument for the adoption of immersive technology in vocational education.

This research also broadens the horizon on the implementation of Mixed Reality technology in the context of education in Indonesia, which is still relatively new and needs more applied research.

2.3 Limitations

The testing sample, although it includes university students and vocational students, is still limited to a specific geographical location (Bandung), so the results may be less representative of the wider population.

The media developed is still focused on multimedia practicum material only, so it has not been tested or adapted for practicum in other fields that may have different needs.

Technical aspects such as hardware compatibility, computer or smartphone specification requirements, and internet access constraints have not been discussed in depth in this study.

Evaluation of long-term use and quantitative impact of learning on academic outcomes has not been conducted, so further studies are needed to measure the effectiveness of learning as a whole.

2.4 Suggesstion

Multi-Platform Development

It is recommended that the development of Mixed Reality-based virtual laboratories be expanded to support various device platforms, including smartphones with low specifications, tablets, and specialized VR/AR devices, so that media accessibility is wider and more inclusive.

Expansion of Practical Materials

In order to optimize the benefits of this media, it is recommended to develop Mixed Reality-based practicum content in other fields of study, such as electrical engineering, automotive, health, and other vocational fields that require hands-on practical experience.

Integration of Learning Evaluation

Future research can add direct evaluation (assessment) features in practicum media, such as interactive quizzes, practical simulation assessments, and tracking student learning progress, making it easier to measure the effectiveness of learning in real-time.

Long-term and Wide-Scale Testing

Further studies are needed with longer-term testing and involving participants from various regions to obtain more representative data and assess the impact of media use on academic outcomes and learning motivation more thoroughly.

Performance and User Experience Optimization

Future development is recommended to focus on improving application performance, reducing bugs, and improving the user interface and user experience to make the media easier to use and more appealing to different types of users.

Collaboration with Industry and Practitioners

Involving industry practitioners and lecturers in the development and testing of media can increase the relevance of practicum content to the needs of the real world of work and enrich the technical and pedagogical aspects of learning media

D. Conclusion

Online learning has emerged as an innovative effort to optimize the use of information technology in education, especially during the pandemic. However, it has not been fully leveraged to meet the practical learning needs, particularly in fields such as multimedia, electronics, automotive, and healthcare, where there are significant barriers. These challenges arise from the lack of digital access to practicum materials and tools, coupled with restrictions on laboratory use during the pandemic. The Mixed Reality (MR) model enables users to experience sound, color, and activities in a virtual space and navigate freely through them (Sugiarto, 2018). This research utilizes the Multimedia Development Life Cycle (MDLC) methodology over an 8 months period, which involves: 1) conducting a literature review on virtual laboratory models for education, 2) developing 3D models for the virtual laboratory design with the integration of MR technologies (augmented reality & virtual reality), and 3) configuring programs for navigation control. By designing a 3D virtual laboratory based on MR, this research aims to create an innovative and interactive multimedia practicum media for distance learning. The media's feasibility was tested using 5 variables, yielding an overall score of 88%, categorized as highly feasible. The detailed feasibility scores for the 5 variables are: Learnability 92%, System Performance 84%, Efficiency 91%, Discoverability 74.2%, and Delight 87.6%.

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F. Author Contribution Statement

AP, conceptualized the research idea, designed the virtual laboratory framework, and led the development of the mixed reality integration. Also responsible for supervising the entire project and reviewing the final manuscript. Focused on the technical implementation of the 3D virtual laboratory, including modeling, and testing the mixed reality system. Contributed to data collection and system refinement based on user feedback

MH, contributed to data collection and system refinement based on user feedback.

MA, contributed to data collection.

References

Abreu, R., & Almeida, F. (2018). E-Learning in Mixed Reality Landscape: Emerging Issues and Key Trends in Scientific Research. *INTED2018 Proceedings*, *1*(March 2018), 6181–6187. https://doi.org/10.21125/inted.2018.1455

Cantarelli, S., Francia, D., Santi, G. M., Liverani, A., & Fiori, M. (2025). Mixed Reality Lab for Assembly and Disassembly of Industrial Products. *Journal of Industrial Information Integration*, 100873. https://doi.org/10.1016/j.jii.2025.100873

Checa, D., Miguel-Alonso, I., & Bustillo, A. (2021). Immersive virtual-reality computer-assembly serious game to enhance autonomous learning. *Virtual Reality*, *0123456789*. https://doi.org/10.1007/s10055-021-00607-1

Chen, S. J., Chen, C. Q., & Shan, X. F. (2024). The Effects of an Immersive Virtual-Reality-Based 3D Modeling Approach on the Creativity and Problem-Solving Tendency of Elementary School Students. *Sustainability (Switzerland)*, *16*, 4092. https://doi.org/10.3390/su16104092

Crogman, H. T., Cano, V. D., Pacheco, E., Sonawane, R. B., & Boroon, R. (2025). Virtual Reality, Augmented Reality, and Mixed Reality in Experiential Learning: Transforming Educational Paradigms. *Education Sciences*, *15*(3), 1–23. https://doi.org/10.3390/educsci15030303

Flavián, C., Ibáñez-Sánchez, S., & Orús, C. (2019). The impact of virtual, augmented and mixed reality technologies on the customer experience. *Journal of Business Research*, *100*(January 2018), 547–560. https://doi.org/10.1016/j.jbusres.2018.10.050

Guzman, J. A. D. E., Thilakarathna, K., & Seneviratne, A. (2019). Security and privacy approaches in mixed reality: A literature survey. *ACM Computing Surveys*, *52*(6). https://doi.org/10.1145/3359626

Hikmah, N., Saridewi, N., & Agung, S. (2017). Penerapan Laboratorium Virtual untuk Meningkatkan Pemahaman Konsep Siswa. *EduChemia (Jurnal Kimia Dan Pendidikan)*, *2*(2), 186. https://doi.org/10.30870/educhemia.v2i2.1608

Jayaputra, A., Tolle, H., & Wardhono, W. S. (2017). Penerapan Mixed Reality Sebagai Sarana Pembelajaran Indera Penglihatan Manusia Menggunakan Teknologi Hologram. *Jurnal*

Pengembangan Teknologi Informasi Dan Ilmu Komputer, *1*(9), 715–722. Google Scholar

Kogler, W., Wood, G., & Kober, S. E. (2021). Effects of electrical brain stimulation on brain indices and presence experience in immersive, interactive virtual reality. *Virtual Reality*. https://doi.org/10.1007/s10055-021-00612-4

Nakamura, K., & Sekiyama, K. (2023). Robot Symbolic Motion Planning and Task Execution Based on Mixed Reality Operation. *IEEE Access*, *11*(October), 112753–112763. https://doi.org/10.1109/ACCESS.2023.3322933

Parveau, M., & Adda, M. (2018). 3iVClass: A new classification method for virtual, augmented and mixed realities. *Procedia Computer Science*, *141*(November 2018), 263–270. https://doi.org/10.1016/j.procs.2018.10.180

Petersen, G. B., Petkakis, G., & Makransky, G. (2022). A study of how immersion and interactivity drive VR learning. *Computers and Education*, *179*(December 2021). https://doi.org/10.1016/j.compedu.2021.104429

Pratama, H., Azman, M. N. A., Kassymova, G. K., & Duisenbayeva, S. S. (2020). The Trend in Using Online Meeting Applications for Learning During the Period of Pandemic COVID-19: A Literature Review. *Journal of Innovation in Educational and Cultural Research*, *1*(2), 58–68. https://doi.org/10.46843/jiecr.v1i2.15

Rahayu, S. L., Fujiati, & Dewi, R. (2018). Educational Games as A learning media of Character Education by Using Multimedia Development Life Cycle (MDLC). *2018 6th International Conference on Cyber and IT Service Management (CITSM)*, 1–4. https://doi.org/10.1109/CITSM.2018.8674288

Rokhsaritalemi, S., Sadeghi-Niaraki, A., & Choi, S. M. (2020). A review on mixed reality: Current trends, challenges and prospects. *Applied Sciences (Switzerland)*, *10*(2). https://doi.org/10.3390/app10020636

Saenong, A., Rahman, M. R., & Makassar, U. D. (2024). Inovasi Mixed Reality Sebagai Media Pembelajaran Dan Pengenalan Kampus Undipa Makassar Berbasis Virtual. *Jurnal Media Informatika*, *6*(1), 703–712. Google Scholar

Sari, S. A., & Sakdiah, H. (2016). The Development of Mind Mapping Media in Flood Material using ADDIE Model. *Journal of Education and Learning (EduLearn)*, *10*(1), 53–62. https://doi.org/10.11591/edulearn.v10i1.3227

Serrano-Ausejo, E., & Mårell-Olsson, E. (2024). Opportunities and challenges of using immersive technologies to support students' spatial ability and 21st-century skills in K-12 education. *Education and Information Technologies*, *29*(5), 5571–5597. https://doi.org/10.1007/s10639-023-11981-5

Smutny, P. (2023). Learning with virtual reality: a market analysis of educational and training applications. *Interactive Learning Environments*, *31*(10), 6133–6146. https://doi.org/10.1080/10494820.2022.2028856

Sugiarto, H. (2018). Penerapan Multimedia Development Life Cycle Pada Aplikasi Pengenalan Abjad Dan Angka. *IJCIT (Indonesian Journal on Computer and Information Technology)*, *3*(1), 26–31. https://doi.org/10.31294/ijcit.v3i1.3753

Syahputra, M. F., Kurniawan, D. S., & Siregar, B. (2020). Interaction Mixed Reality Rare Animal Indonesia with Voice Input Using Microsoft Hololens. *Journal of Physics: Conference Series*, *1566*(1). https://doi.org/10.1088/1742-6596/1566/1/012033

Vaughan, N., Gabrys, B., Review, V. D.-C. S., & 2016, U. (2016). An overview of self-adaptive technologies within virtual reality training Virtual reality. *Elsevier*, *22*, 65–87. https://doi.org/10.1016/j.cosrev.2016.09.001

Wibowo, T. S., Limken, V., & Mada Baloi Sei Ladi Batam, J. (2021). Designing Learning Media for Bataknese Cuisine Using Multimedia Development Life Cycle (Mdlc) Method. *Journal of Information System and Technology*, *02*(02), 56–63. https://doi.org/10.37253/joint.v2i2.6072

Widodo, A. Y. P., Yennita, Y., Azhar, A., & Islami, N. (2019). Development of Physics Learning Media on Rotational Materials Based on Interactive Multimedia. *Journal of Physics: Conference Series*, *1351*(1). https://doi.org/10.1088/1742-6596/1351/1/012057

Zakharov, P. V., Vdovin, R. S., Markidonov, A. V., Kochkin, A. S., & Vdovin, A. S. (2020). Virtual and mixed reality in the study of the geometry of the crystal lattice. *Journal of Physics: Conference Series*, *1515*(2). https://doi.org/10.1088/1742-6596/1515/2/022001