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DEVELOPMENT OF VIRTUAL REALITY-BASED MULTIMEDIA MODELING AND SIMULATION LEARNING TO ACHIEVE MEANINGFUL LEARNING

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ABSTRACT
This research aims to develop Virtual Reality (VR)-based learning multimedia for the Modeling and Simulation course as an effort to achieve *meaningful learning* in higher education. The study employed a Research and Development (R&D) method consisting of several stages, including needs analysis, design, validation, and product testing. Data analysis was conducted through the validity test of the practicality questionnaire, expert validation of the media, and practicality testing by users. The validity test of the instrument involving 63 respondents showed that all items were valid at a 5% significance level. Expert validation results indicated an average validity score of 91%, categorized as highly valid, covering aspects of material content, visual communication, user design, and software utilization. The practicality test conducted with 63 students of the Informatics and Computer Education Study Program revealed that the VR-based learning multimedia was highly practical, easy to use, and effective in enhancing students' understanding of Modeling and Simulation concepts. The interface design dominated by blue tones provided a calm and comfortable learning atmosphere. Based on these findings, it can be concluded that the Virtual Reality-based learning multimedia developed in this study is highly valid and practical, and therefore suitable for broader implementation as an innovative learning medium to enhance the quality and meaningfulness of students' learning experiences.

INTRODUCTION

The rapid advancement of Information and Communication Technology (ICT) has significantly transformed various aspects of human life, including education (Prasetyo, 2020). The integration of technology in learning environments offers great opportunities for educators to create more engaging, interactive, and meaningful learning experiences. One of the most promising innovations is the use of Virtual Reality (VR)-based learning multimedia, which can enhance learners' engagement, motivation, and understanding of complex concepts (Anderson & Shanks, 2021; Lin et al., 2020). The application of VR in higher education is not merely intended to increase student participation, but also to foster meaningful learning experiences that are aligned with the demands of 21st-century education (Sari, 2022).

In modern education, instructors are required to select learning media that suit students' characteristics and learning objectives. However, in practice, many educators still focus primarily on delivering content without paying sufficient attention to student engagement and the meaningfulness of the learning process (Gunawan, 2019). Educators should play an active role in creating collaborative and participatory learning environments (Hidayat, 2021) and understand effective strategies for conveying knowledge so that it becomes easier for students to comprehend (Nurhayati, 2020). Therefore, teachers must be capable of selecting and developing relevant and effective learning multimedia, adapted to the available resources and learning context (Mustika, 2022).

The development of learning multimedia integrated with VR technology offers tremendous potential to enhance the learning experience, particularly in the Modeling and Simulation course. These two concepts play a vital role in higher education, especially in engineering, science, and technology disciplines. Modeling helps students understand complex concepts through intuitive visual representations, while simulation provides opportunities to apply those concepts in near-real-world contexts. Nevertheless, the implementation of these methods still faces challenges, particularly regarding the use of learning media that actively engage students throughout the learning process. Previous studies have shown that VR-based multimedia technology can significantly increase students' motivation and engagement during learning (Lee & Wong, 2021). VR allows for a more personalized and adaptive learning experience, which is essential for meeting individual learner needs (Rahman et al., 2022). However, prior research still demonstrates limitations, particularly in the practical implementation and evaluation of VR-based multimedia effectiveness in higher education settings.

This phenomenon indicates a gap between the potential and actual implementation of modern educational technology. Many higher education institutions have not yet fully optimized the use of VR technology as an integral part of their instructional strategies. Most existing studies tend to focus on the technological potential rather than examining its implementation, effectiveness, and impact on students' learning experiences. Furthermore, there is still a scarcity of comprehensive studies that investigate the development of learning multimedia integrating modeling and simulation with VR technology. Based on these gaps, this study aims to develop an innovative Virtual Reality-based learning multimedia for the Modeling and Simulation course to realize meaningful learning. This research is expected to contribute to the development of adaptive, effective, and technology-based instructional models relevant to the needs of 21st-century education. The urgency of this study is further supported by the growing adoption of VR technology worldwide. According to a report by the International Data Corporation (IDC), the global VR market is projected to reach 198 billion USD by 2025 (International Data Corporation, 2023), indicating a substantial opportunity for the integration of VR into education.

Virtual Reality (VR) has emerged as one of the most innovative technologies in the field of education, providing immersive learning environments that enhance engagement, motivation, and understanding among students. VR enables learners to experience abstract or complex concepts through realistic simulations, which promotes deeper cognitive processing (Lin et al., 2020). According to Anderson and Shanks (2021), immersive VR environments can bridge the gap between theory and practice by allowing students to interact directly with learning

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materials in simulated real-world contexts. This aligns with constructivist learning theories, which emphasize that learners build knowledge through active engagement and experiential learning. The application of VR in higher education also supports the principles of meaningful learning, as proposed by Ausubel, where new information becomes meaningful when it connects with existing knowledge. Sari (2022) further emphasizes that VR facilitates the creation of personalized and context-rich learning experiences, making learning more engaging and relevant to students' needs in the 21st century.

Multimedia learning integrates various forms of information—text, images, audio, animation, and interactivity—to facilitate effective knowledge construction. Gunawan (2019) highlights that digital multimedia enhances students' ability to comprehend complex materials, particularly when combined with interactive features. Similarly, Hidayat (2021) argues that multimedia-based learning promotes collaboration and participation, especially when learners are actively involved in exploring digital content.

Furthermore, Mustika (2022) notes that effective multimedia design should align with pedagogical principles, ensuring that each component—visuals, narration, and interaction—contributes meaningfully to learning outcomes. Instructors, therefore, play a crucial role in selecting and developing appropriate multimedia tools that suit learners' cognitive abilities and contextual needs. Nurhayati (2020) adds that clear instructional design and intuitive navigation are key to maximizing the educational impact of multimedia.

Modeling and simulation have long been recognized as essential instructional strategies in engineering, science, and technology disciplines. Through modeling, learners can visualize and manipulate representations of abstract systems, while simulation allows them to experiment within controlled, risk-free environments (Prasetyo, 2020). These strategies encourage active learning by enabling students to test hypotheses, analyze outcomes, and reflect on their understanding. However, traditional modeling and simulation tools are often limited in their ability to fully immerse learners. By integrating these approaches with VR, educators can provide richer, more authentic experiences that mimic real-world scenarios, thereby deepening conceptual understanding (Rahman et al., 2022). Such integration transforms passive observation into interactive exploration, aligning with current educational paradigms that prioritize experiential and inquiry-based learning.

Empirical studies consistently show that VR-based multimedia can significantly enhance learning outcomes. Lee and Wong (2021) found that students exposed to VR learning environments demonstrate higher motivation, greater retention, and improved problem-solving skills compared to those using conventional methods. Similarly, Rahman et al. (2022) reported that personalized VR environments foster adaptive learning, allowing each learner to progress at their own pace and according to their individual learning style. Despite these advantages, prior research indicates that the practical implementation of VR in educational settings remains limited. Many institutions face challenges related to technical infrastructure, instructional design, and teacher readiness (International Data Corporation, 2023). Consequently, there is a pressing need for research that not only explores the theoretical potential of VR but also evaluates its practical effectiveness in specific subject areas, such as modeling and simulation.

While numerous studies have explored the general benefits of VR in education, few have focused on its integration with modeling and simulation as a unified multimedia learning system. The lack of empirical evidence on the development, validation, and practicality of such multimedia tools presents a significant research gap. Moreover, most studies emphasize learner engagement or motivation, with limited attention to design validation and usability testing (Lin et al., 2020; Sari, 2022). This study addresses these gaps by developing, validating, and testing the practicality of a VR-based multimedia learning tool for the Modeling and Simulation course. The conceptual framework integrates VR technology, multimedia design principles, and meaningful learning theory to produce an interactive, validated, and practical educational product suitable for higher education.

RESEARCH METHOD

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This study employed a Research and Development (R&D) approach using the 4D model (Define, Design, Develop, Disseminate) developed by Thiagarajan, Semmel, and Semmel (1974). The 4D model was chosen because it provides a systematic framework for producing validated, practical, and effective educational products.
The purpose of this research is to develop a Virtual Reality (VR)-based learning multimedia for the *Modeling and Simulation* course to foster *meaningful learning* in higher education. The four stages of the 4D model implemented in this study are as follows:

1. Define – identifying learning needs and problems.
2. Design – creating the initial prototype of the multimedia.
3. Develop – validating, revising, and testing the product.
4. Disseminate – implementing and sharing the final product for broader use.

Research Subjects and Location
The subjects of this study were 63 students of the Informatics and Computer Education Study Program (PTIK) who were currently taking or atau pakai and had completed the *Modeling and Simulation* course. The sample was selected using purposive sampling, based on their relevance and experience with the course.
The product validation was carried out by two experts, one specializing in educational technology and the other in multimedia design, who assessed both content and visual aspects. The research was conducted over one semester at the university's PTIK program.
Research Procedures
1. Define Stage
The purpose of this stage was to identify and define the instructional needs. Activities included:

a) Analyzing the curriculum and learning outcomes of the *Modeling and Simulation* course.
b) Identifying student characteristics and learning challenges.
c) Reviewing instructional materials and determining key concepts to be visualized through VR.
d) Assessing available facilities and technological infrastructure.

The results of this stage served as the foundation for designing the initial structure of the VR-based multimedia.
2. Design Stage
At this stage, an initial prototype of the VR learning multimedia was developed. The activities consisted of:

a) Designing the instructional structure based on *meaningful learning* principles.
b) Creating storyboards, navigation maps, and user interface layouts.
c) Selecting development tools such as *Unity 3D*, *Blender*, and *Adobe Premiere Pro*.
d) Developing research instruments, including expert validation sheets and practicality questionnaires.

The output of this phase was a functional prototype of the VR-based multimedia ready for expert review.
3. Develop Stage
The development phase focused on validating, revising, and testing the product. Activities included:

a) Expert validation, conducted by two specialists evaluating four aspects: content substance, visual communication, user design, and software utilization.
b) Product revision, based on feedback and recommendations from the validators.
c) Practicality testing, conducted with 63 students to assess the usability, attractiveness, and instructional effectiveness of the multimedia.

The results of this phase determined whether the product was ready for broader implementation.
4. Disseminate Stage
The dissemination stage aimed to introduce and apply the developed multimedia to a wider audience. Activities included:

a) Sharing the product with other lecturers and students within the study program.
b) Presenting findings at academic seminars and educational technology workshops.

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c) Preparing the research for publication in peer-reviewed journals to promote wider adoption of VR-based learning tools.

Research Instruments

The instruments used in this study included:

a) Expert Validation Sheets – to evaluate the validity of content, visual design, user interface, and software functionality.
b) Practicality Questionnaires – to assess the usability, clarity, and perceived usefulness of the multimedia by students.
c) Observation and Field Notes – to record user interactions and behaviors during testing sessions.
d) All instruments were developed based on established criteria for media validity and practicality in educational product development.

Data Collection Techniques

Data were collected using the following techniques:

a) Expert validation to measure the content and design validity of the multimedia.
b) Questionnaires distributed to students to evaluate the practicality and usability of the product.
c) Observation during the trial sessions to gather qualitative insights about user interaction and engagement.

Data Analysis Technique

The data analysis technique uses descriptive analysis with a percentage of validity and practicality. The analysis of the validity and practicality of an animated video based on Randai local wisdom uses analysis with percentage analysis using formula (1).

$$\frac{number\ of\ scores\ obtained}{number\ of\ scores\ max} x100\% \ldots\ldots\ldots\ldots(1);$$

The content validation assessment criteria are shown in Table 1.

Table 1. Validation Test Score Criteria

Value (%)	Category
90 - 100	Very valid
80 - 89	Valid
65 - 79	Moderately valid
55 - 64	Less valid
≤ 54	Very invalid

Practicality analysis using a questionnaire to see the benefits of using local wisdom-based learning animation videos practicality assessment criteria as in Table 2.

Table 2 Practicality Test Criteria

Value (%)	Category
86 - 100	Very Practical
76 - 85	Practical
60 - 75	Practical Enough
55 - 59	Not Practical
≤ 54	Not Very Practical

RESULT AND DISCUSSION

1. Define Phase

During the define phase, a comprehensive analysis was conducted to identify the needs for software, hardware, and related resources required to develop the Virtual Reality (VR)-based learning multimedia. The software selected was a platform capable of supporting educational VR environments in this case, Lapentor, which enables panoramic 3D visual presentation. The 3D images were captured using panoramic photography techniques, while the

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hardware analysis determined the minimum and optimal specifications, such as computers equipped with high-performance GPUs, to ensure smooth media rendering and interactivity. A literature review was also conducted to establish the theoretical foundation of the research. Learning media are defined as intermediary tools used by teachers to facilitate the delivery of instructional content (Arsyad, 2019). They play a crucial role in stimulating students' cognitive and affective engagement, enhancing motivation, and improving comprehension (Sanjaya, 2020; Munadi, 2021). Several scholars have emphasized that instructional media can positively influence learners' behavior and creativity, making learning experiences more dynamic and effective (Hamalik, 2020). Thus, learning media can be understood as teaching aids that help educators convey content efficiently, including interactive multimedia such as VR-based applications.

Multimedia learning**,** which combines text, images, audio, and video, enhances comprehension by integrating multiple sensory inputs (Mayer, 2009). Previous studies (Clark & Mayer, 2016; Moreno, 2019) have shown that multimedia-based learning increases student motivation and engagement while aligning with constructivist principles. In higher education, multimedia has been proven effective in improving conceptual understanding and supporting various learning styles (Huang et al., 2020). Virtual Reality (VR) is defined as a computer-generated environment that enables users to interact with simulated three-dimensional spaces. In education, VR provides immersive and interactive learning experiences that deepen conceptual understanding and motivation (Freina & Ott, 2015). Empirical studies demonstrate that the use of VR in science learning enhances student engagement and performance compared to traditional methods (Makransky & Lilleholt, 2018). Moreover, VR allows for safe and cost-effective simulations of activities that would be dangerous, expensive, or logistically challenging in real life, such as laboratory experiments (Radianti et al., 2020).

Integrating multimedia and VR creates a holistic and effective learning experience by combining visual engagement, interactivity, and real-time feedback (Zhao et al., 2021). The combination of VR with Artificial Intelligence (AI) and multimedia tools can improve critical thinking and collaborative learning (Lee & Wong, 2021). Studies also emphasize that teacher training is essential to maximize the pedagogical potential of these technologies (Rahman et al., 2022).

In the context of Modeling and Simulation, these technologies allow learners to visualize abstract systems, manipulate variables, and analyze causal relationships (Prasetyo, 2020). Recent advancements in AI-assisted modeling and simulation have produced real-time physics systems in VR, which improve conceptual understanding by over 40% compared to traditional methods (Wang et al., 2019). Multi-scale modeling frameworks (Keller & Zhang, 2020) have also enabled learners to explore systems from macro to micro levels within the same virtual environment, offering significant potential for science and engineering education. Moreover, dynamic system modeling and VR visualization enhance learners' understanding of complex interactions through 3D visualization and direct manipulation of virtual objects (Yoon et al., 2021). Virtual simulation environments reduce laboratory accidents by up to 78%, minimize setup time, and cut laboratory costs (Feng et al., 2020).

2. Design Phase

The design phase involved the creation of the storyboard and the overall multimedia VR interface, as illustrated *Storyboard of Queue Simulation*. The content focused on simulating queuing scenarios relevant to the *Modeling and Simulation* course. The storyboard outlined the flow of scenes, user navigation, and placement of instructional content, ensuring alignment between pedagogical objectives and visual presentation.

3. Develop Phase

The develop phase included validation of the VR-based multimedia prototype by subject matter experts and media experts.

3D Image Capture

The primary learning material was a queue simulation activity conducted by students at the Faculty of Teacher Training and Education, Universitas Bung Hatta. Four queue scenarios were created involving four, three, two, and one student respectively each captured using panoramic 3D photography. These images formed the core scenes of the VR simulation.

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Integration Using Lapentor

The captured 3D scenes were integrated into the Lapentor VR platform to form an interactive learning environment. The structure of the VR simulation is presented, which includes key elements such as introduction scenes, queue simulations instructional materials**,** discussion questions, and navigation controls. Additional features such as WebVR**,** gyroscope control, intro pop-up windows, and video hotspots were included to enhance immersion and usability.

Data Analysis Results

Data analysis included instrument validation**,** media validation**,** and practicality testing**.**

Instrument Validity

The practicality questionnaire items were tested for validity using a significance level of 0.05 with 63 respondents. The critical r-table value was 0.367**,** and all items achieved r-count > r-table, indicating that each item was valid and suitable for measuring practicality.

Media Validity

The multimedia was validated by two experts, and the results are summarized in Table 3.

Table 3. Validiy Result

Assessment Aspect	Expert 1	Expert 2	Total	Validity (%)	Category
Content Substance	12	11	23	88%	Highly Valid
Visual Communication Design	16	17	33	87%	Highly Valid
User Interface Design	26	25	51	94%	Highly Valid
Software Utilization	9	11	21	91%	Highly Valid
Average			**128**	**91%**	**Highly Valid**

These results indicate that the VR-based learning multimedia is highly valid in all aspects. Expert comments suggested that while the content was accurate and readable, the language in the evaluation section should be refined to be less rigid. The visual design was considered effective, though experts recommended using more consistent and clearer typography. Navigation, animation, and layout were rated as "good" by both validators, while the overall interface design received the highest scores, confirming that the multimedia was ready for user trials. Additionally, software utilization was rated at the maximum score (4**)** by both validators, indicating originality and appropriate use of supporting software such as databases and interactive plugins.

Practicality Analysis

The practicality test was conducted with 63 PTIK students enrolled in or having completed the *Modeling and Simulation* course. The results showed that the VR-based multimedia achieved the **"**Highly Practical**"** category, indicating that students found it easy to use, engaging, and effective for learning. Students appreciated the dominant blue color scheme, which created a calm and comfortable atmosphere during learning sessions and assessments. This finding aligns with research indicating that color psychology in media design influences emotional stability and focus during learning activities (Nasir et al., 2020).

Overall, the multimedia product developed in this study demonstrated high validity and practicality, making it suitable for broader implementation in higher education learning environments. These findings are consistent with prior research (Rahman et al., 2022; Lee & Wong, 2021), which emphasized that validated and practical VR-based applications can be effectively implemented according to instructional needs. he results of this study demonstrate that the development of Virtual Reality (VR)-based learning multimedia for the Modeling and Simulation course successfully met the criteria of validity and practicality, thus supporting its use as an effective instructional medium to achieve *meaningful learning*. The validation results showed that the developed multimedia achieved a high level of validity (91%) across all evaluation aspects—content substance, visual communication, user interface design, and software utilization. This finding aligns with previous studies (Anderson & Shanks, 2021; Lin et al., 2020) which state

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that learning media that combine visual, auditory, and interactive elements can significantly enhance the clarity of learning materials and improve learner engagement. The high validity score also confirms that the instructional content, visual layout, and technical implementation are consistent with pedagogical principles and user-centered design.The expert feedback indicated that the material was accurate and relevant, though minor adjustments in language tone were suggested to improve accessibility. Similarly, consistent typography and color usage were recommended to enhance readability and aesthetic coherence. These observations are consistent with the findings of Hidayat (2021), who emphasized that visual consistency and clarity are crucial in multimedia learning design to support students' focus and reduce cognitive overload. Furthermore, the software utilization aspect received the highest score, indicating originality and appropriate use of VR technology. This suggests that the product effectively integrates the potential of VR as an immersive learning medium. According to Freina and Ott (2015), VR-based environments create authentic learning experiences by simulating real-world contexts, allowing learners to engage actively with complex concepts through experiential interaction. In this study, the VR-based queue simulation allowed students to visualize and interact with abstract modeling concepts, bridging the gap between theoretical knowledge and practical application. The practicality results also showed that the developed multimedia was categorized as **"**Highly Practical" based on students' responses. Students perceived the VR-based media as easy to navigate, visually appealing, and effective in improving their understanding of the course material. This supports earlier findings by Lee and Wong (2021), who reported that VR-based learning tools enhance learners' motivation and retention by providing interactive and immersive experiences. The calming blue color scheme also contributed to a comfortable learning atmosphere, in line with research on color psychology in educational design (Nasir et al., 2020).

The results further support the theory of Meaningful Learning (Ausubel, 1968), where learners connect new information with prior knowledge through active engagement and contextual experiences. The VR-based multimedia enabled students to learn through visualization, simulation, and interaction—three elements that promote deeper understanding and retention (Mayer, 2009). This integration of *constructivist* and *experiential learning principles* shows that VR technology can serve not only as an instructional tool but also as a cognitive scaffold that enhances conceptual understanding. Overall, the developed multimedia provides evidence that combining Modeling and Simulation pedagogy with VR technology can effectively improve learning quality in higher education. The findings confirm the conclusions of Rahman et al. (2022) and Sari (2022), who noted that validated and practical multimedia applications based on immersive technologies can foster more personalized and meaningful learning experiences.

CONCLUSION

This study successfully developed a Virtual Reality (VR)-based multimedia learning tool for the *Modeling and Simulation* course using the 4D development model (Define, Design, Develop, and Disseminate)**.** Based on expert validation and student practicality testing, the results show that:1) The instrument for measuring practicality was valid and reliable, 2) The VR-based multimedia achieved an average validity of 91%**,** categorized as *Highly Valid*. 3) The practicality test involving 63 students resulted in the *Highly Practical* category. 4)The developed multimedia effectively supports *meaningful learning* through interactive visualization, immersive engagement, and conceptual reinforcement.

The research demonstrates that integrating Virtual Reality into multimedia learning design can bridge abstract modeling concepts with real-world application, creating a more interactive and student-centered learning environment. The combination of VR visualization, multimedia elements, and simulation-based content provides a holistic approach to 21st-century education that enhances motivation, creativity, and conceptual mastery.

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