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ORIGINAL

Integration of Artificial Intelligence in Virtual Reality-Based Learning

Integración de la Inteligencia Artificial en el Aprendizaje Basado en la Realidad Virtual

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ABSTRACT

The integration of Artificial Intelligence (AI) and Virtual Reality (VR) in education presents a promising opportunity to create immersive and adaptive learning environments, but research on the integration of both is very rare for the case of elementary school education. Most studies only focus on the standalone study of one of the technologies. The research focuses on analyzing the impact and relationship between the integration of AI in VR learning environments over time, hence it will employ longitudinal data collection and time series analysis to understand trends and patterns. The research subjects for this study were fifth grade elementary school students, aged between 11 and 12 years. This research involves observation and data collection in the form of learning outcome tests at several points in time to determine how the integration of AI and VR develops in the classroom and affects learning outcomes. Data was analyzed using trend analysis with a time series approach. The results of the study show that the integration of AI in VR-based learning gives a positive trend to student learning outcomes. The research findings show that the Quadratic Trend Model (QTM) is the most accurate model for measuring student learning outcome trends.

Keywords: Artificial Intelligence; Virtual Reality; Learning Outcomes; Elementary School.

RESUMEN

La integración de la Inteligencia Artificial (IA) y la Realidad Virtual (RV) en la educación presenta una oportunidad prometedora para crear entornos de aprendizaje inmersivos y adaptativos, pero la investigación sobre la integración de ambas es muy escasa para el caso de la educación primaria. La mayoría de los estudios se centran únicamente en el estudio independiente de una de las tecnologías. La investigación se centra en analizar el impacto y la relación entre la integración de la IA en los entornos de aprendizaje de RV a lo largo del tiempo, por lo que empleará la recopilación de datos longitudinales y el análisis de series temporales para comprender las tendencias y los patrones. Los sujetos de investigación de este estudio fueron alumnos de quinto curso de primaria, con edades comprendidas entre los 11 y los 12 años. Esta investigación implica la observación y la recopilación de datos en forma de pruebas de resultados del aprendizaje en varios momentos para determinar cómo se desarrolla la integración de la IA y la RV en el aula y cómo afecta a los resultados del aprendizaje. Los datos se analizaron mediante un análisis de tendencias con un enfoque de series temporales. Los resultados del estudio muestran que la integración de la IA en el aprendizaje basado en la RV da una tendencia positiva a los resultados de aprendizaje de los alumnos. Las conclusiones de la investigación muestran que el modelo de tendencia cuadrática (QTM) es el más preciso para medir las tendencias de los resultados del aprendizaje de los estudiantes.

Palabras clave: Inteligencia Artificial; Realidad Virtual; Resultados de Aprendizaje; Escuela Primaria.

INTRODUCTION

The integration of Artificial Intelligence (AI) and Virtual Reality (VR) technologies in educational environments has gained significant attention in recent years. Virtual Reality-based learning offers immersive and interactive experiences, providing students with a simulated environment to enhance their understanding of complex concepts.[1,2] Studies highlight the potential of VR to improve engagement and learning outcomes across various educational levels.[3,4] Meanwhile, AI complements VR by personalizing the learning experience, analyzing student behavior, and offering adaptive content delivery.[5,6]

Elementary education, being foundational to cognitive and social development, benefits immensely from such technological advancements. Emerging evidence suggests that AI-driven tools can identify learning gaps and facilitate tailored instruction,[7,8] while VR environments promote active learning and experiential understanding.[9,10] However, despite the proven benefits, the application of AI and VR in elementary school education remains limited.[11,12] This gap necessitates exploration into their combined potential to transform early learning environments.

The recent research emphasizes the application of AI and VR as complementary technologies in education.[13,14] AI-powered systems have been employed to analyze student interactions, identify patterns, and predict learning outcomes.[15] For instance, AI-driven chatbots and recommendation engines are used to facilitate real-time feedback and suggest targeted learning materials.[16] In parallel, VR has been deployed to create immersive simulations, allowing students to interact with virtual environments for enhanced concept retention.[17]

Studies demonstrate that VR, coupled with AI's data-driven personalization, has the potential to redefine learning processes by aligning teaching methodologies with individual learner profiles.[18] VR technology can provide a more engaging and interactive learning experience, particularly in STEM education and language acquisition, where visualization and experiential learning are crucial.[19]

However, the adoption of such integrated systems in elementary schools remains nascent, with challenges such as cost, accessibility, and teacher training hindering widespread implementation.[20] Despite these hurdles, pilot studies illustrate the success of AI-VR systems in fostering interactive learning environments.[21] For instance, VR-based learning has been shown to improve student motivation, retention, and understanding, as well as promote collaboration and problem-solving skills.[22]

The existing literature underscores the individual effectiveness of Artificial Intelligence (AI) and Virtual Reality (VR) in enhancing educational outcomes. AI has been shown to effectively monitor student progress through analytics, enabling educators to tailor interventions and support based on individual learning trajectories.[23] For instance, AI systems can analyze data from student interactions to provide real-time feedback, which is crucial for fostering engagement and improving learning outcomes.[24] Similarly, VR has been recognized for its capacity to facilitate experiential learning by replicating real-world scenarios, thereby allowing students to engage in immersive learning experiences that enhance retention and understanding.[25]

Despite these advancements, there remains a notable gap in research exploring the synergy of AI and VR within a unified framework, particularly in the context of elementary education. Most studies have predominantly focused on the standalone applications of either AI or VR, leaving a critical void in understanding how their integration could address broader educational challenges.[26] This lack of comprehensive research is particularly concerning given that elementary school students, who are at a pivotal stage in cognitive and social development, could significantly benefit from an AI-VR hybrid learning environment. Such an environment could provide personalized learning experiences that cater to the diverse needs of young learners.[27]

Despite the promising potential of AI and VR, there is a notable lack of research focusing on their integration within elementary education. Most existing studies tend to concentrate on standalone applications of either technology, leaving a critical gap in understanding how their combined use can address broader educational challenges.[28,29] This research seeks to fill that gap by designing and evaluating a prototype AI-VR learning system, conducting pilot implementations in elementary classrooms, and assessing its impact on student engagement and academic outcomes.[30]

By addressing both technological and pedagogical aspects, this study aims to contribute to the broader discourse on the role of emerging technologies in foundational education. The findings from this research could provide valuable insights into the practical applications of AI and VR in creating adaptive learning environments that enhance educational experiences for young learners.[31] Ultimately, this integration has the potential to redefine educational methodologies, making learning more personalized, engaging, and effective for elementary school students.

METHOD

This type of research can be classified as quantitative research. Specifically, this research focuses on analyzing the impact and relationship between AI integration in VR learning environments over time, therefore this research has used longitudinal data collection and time series analysis to understand trends and patterns. This research uses an explanatory research design. The purpose of this design is to identify and explain the relationship between the integration of artificial intelligence in virtual reality-based learning and its effects on students' academic performance and engagement over time. This research involves observation and data collection in the form of learning outcome tests at several points in time to determine how the integration of AI and VR develops in the classroom and affects learning outcomes.

The research subjects for this study were fifth grade elementary school students, aged between 11 and 12 years. This study has focused on students enrolled in elementary schools that have integrated AI and VR learning environments into their curriculum. Schools have been selected based on their adoption of these technologies, and students' academic performance, engagement, and learning behavior will be the focus of data collection. Teachers' qualitative assessments and observational notes on students' participation, collaboration, and performance in the VR learning environment are also needed to support the previous core data on student learning outcomes.

In the context of this study has used trend analysis to evaluate the impact of integrating Artificial Intelligence (AI) in Virtual Reality (VR) learning environments, the use of statistical analysis methods is essential to predict and estimate educational outcomes over time. This study has used Minitab 18 for data processing and will compare four trend analysis models: Linear Trend Model (LTM), Quadratic Trend Model (QTM), Growth Curve Model (GLM), and S-Curve Trend Model (SCTM). Below, we present the equations for each of these models that support the methodology and statistical techniques used in this study.

Linear Trend Model (LTM)

$Y_t = a + b_t$

Quadratic Trend Model (QTM)

$Y_t = a + b_t + c_t^2$

Growth Curve Model (GCM)

$Y_t = a \,.\, b_t$

S-Curve Trend Model (SCTM)

$Y_t = 10^a \,/\, (b_0 + b_1 . b_2^t)$

To determine the ideal model for analyzing AI integration in VR learning environments, the measurement error estimation criterion has been used. This criterion states that the best model is the one that exhibits the smallest measurement error. In this study, three specific approaches have been used to analyze the measurement error estimation: Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD), and Mean Squared Deviation (MSD).

RESULTS

In the rapidly developing digital era, technology has become a major force in changing the paradigm of education around the world. One of the latest innovations that promises a significant impact is the integration of AI and VR in the learning process. This concept not only introduces a more immersive and engaging learning experience for students, but also offers the potential to improve the efficiency and effectiveness of teaching. As technology advances, schools around the world are beginning to adopt the use of AI and VR to support more interactive and adaptive learning, especially at the elementary level.

This study aims to explore the long-term impact of the use of AI integrated with VR in the context of elementary school learning. Using a time series approach, this study analyzes how student interactions with AI-supported VR-based learning environments affect academic performance and student engagement levels over time. By collecting data periodically from schools that have implemented this technology, this study seeks to explore the extent to which the integration of this technology can change the dynamics of learning and encourage better academic development in students.

The learning process in this study was facilitated by a learning management system (LMS) developed by the research team itself. The LMS developed was named "Nusa Virtual Reality". The LMS developed has three roles in it. The first role is as an admin who is in charge of making technical arrangements in the LMS. The second role is as a teacher who is in charge of arranging learning devices such as materials, assignment activities, assessments and other learning needs. The third role is a student who is in charge of following the material according to the directions programmed by the class teacher. The following is a figure of the LMS home page for logging in as an admin, teacher, or student.

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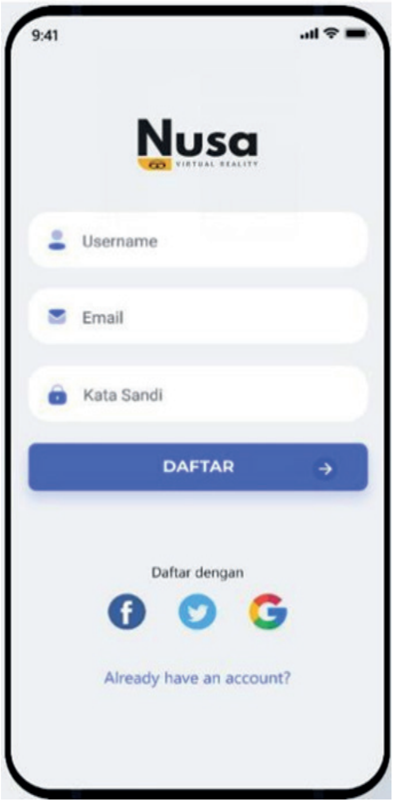

Figure 1. LMS Login Page

Each user, both teachers and students, must first register an account before carrying out learning activities. All materials taught to students have been listed in the LMS which has been arranged in such a way by the research in coordination with the class teacher based on the learning objectives to be achieved. After having an account, the user can log in to enter the main page of the LMS. This main page contains participant identities, learning materials, quizzes and discussion forums that can be used to support learning interactions. The following is an illustration of the main page of the LMS used in this study.

Figure 2. LMS Main Page

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This LMS is the main tool in this study to integrate AR and VR in one learning set. VR integration is linked in each material. All materials in the LMS have at least one video containing the main learning material. The video is integrated in YouTube 360° which students follow using virtual reality glasses. The following is an illustration of student involvement in following the material with VR.

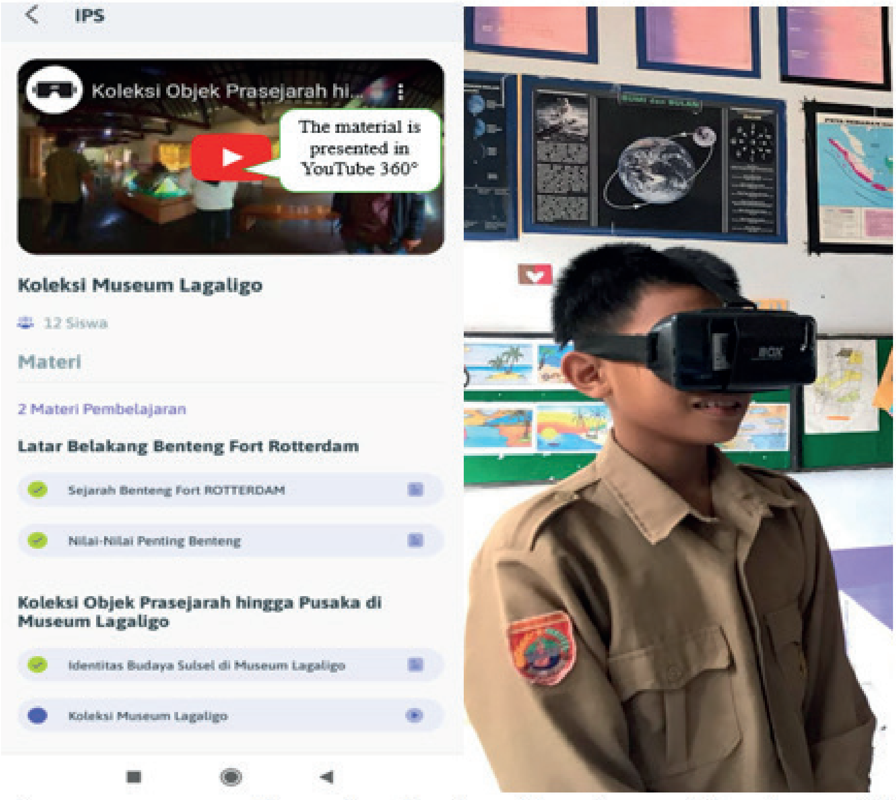

Figure 3. Student Activities Studying Material Integrated with VR Technology

Figure 3 presents an illustration of VR-based learning. Each learning topic has supplementary materials that students follow in the VR application. Furthermore, related to the integration of AI in learning, it can be seen in the LMS component in the chat section. To strengthen students' experience and understanding in learning, the LMS menu provides a chat option. In this chat menu, there are two chat options. The first option is to ask the teacher and the second option is to ask Nusa AI. The following is an illustration of the chat menu in the LMS used by students to study the material.

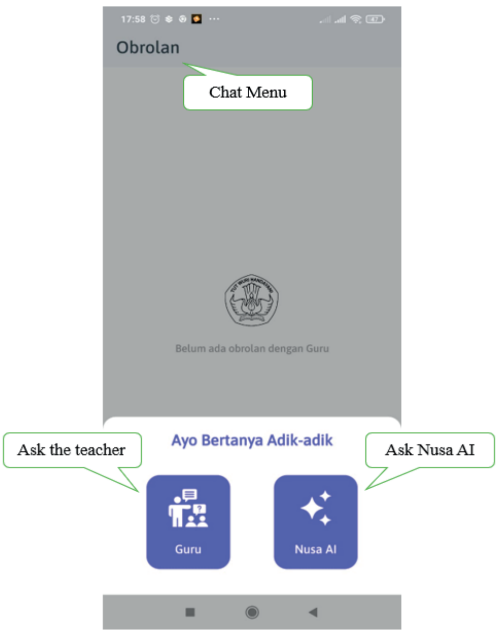

Figure 4. AI Integration in LMS

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Figure 4 presents the role of AI in learning observed in this study. In the chat menu, students are faced with two choices. Chat with the teacher or the second choice is to ask Nusa AI. If students choose to ask the teacher, the question will be written and sent to the teacher's account to be responded to. This choice will of course wait for a response from the teacher. The only drawback is that if the teacher is not active on their account, the response will likely be a little slower. However, if students choose to ask AI, they will get a response in real time. The following is an example of the interaction process with AI during the learning process.

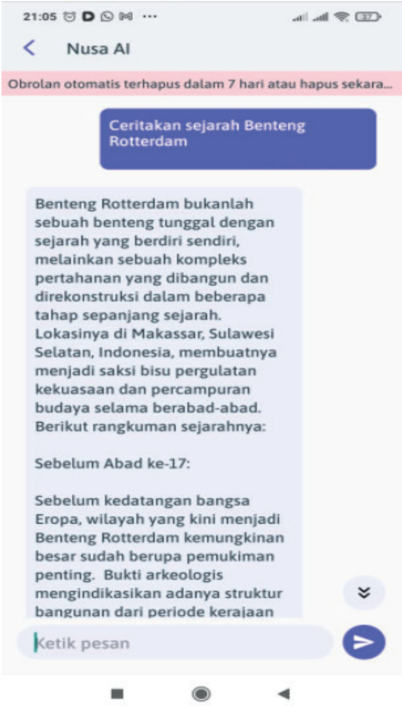

Figure 5. Utilizing AI Chatbots to Strengthen Student Understanding

Figure 5 shows one example of a student's effort to understand the material by utilizing AI chatbots that have been provided in the LMS. This menu is provided to accommodate the role of teachers who cannot be active at all times. Sometimes students need an immediate response to answer their questions but the teacher is not active in their account. Therefore, the presence of AI provides a solution to make it easier for students to receive information immediately.

The next important thing is the findings on time series analysis. This test was conducted to prove the effectiveness of AI integration in VR-based learning in this study. As explained in the method section, there are four modules tested to prove the effectiveness of AI integration in VR-based learning. The models in question are Linear Trend Model (LTM), Quadratic Trend Model (QTM), Growth Curve Model (GCM), and S-Curve Trend Model (SCTM). The first test was conducted on LTM. Based on empirical data successfully collected from the field, the following is the result of trend analysis based on LTM.

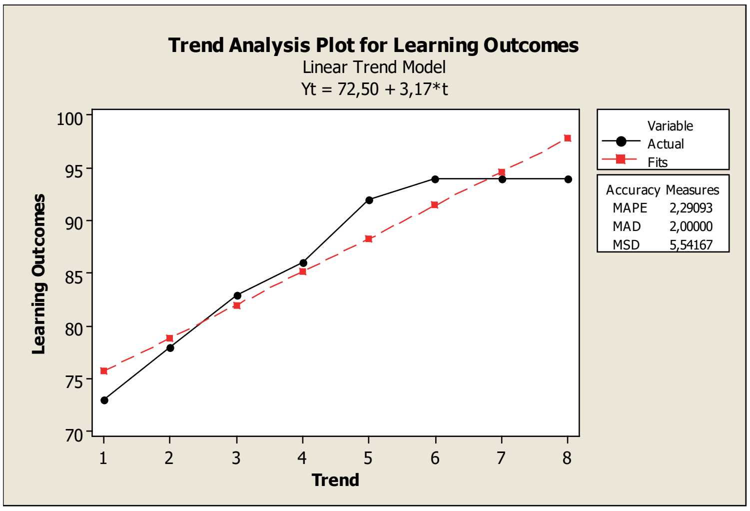

Figure 6. Analysis Results with Linear Trend Model

Figure 6 shows the trend of student learning outcomes after learning with AI integration in VR-based learning based on LTM. From these findings, some information can be explained, namely the black line shows empirical data in the form of student learning outcome trends from the field, while the red line shows the expected model based on the Linear Trend Model (LTM). When viewed from the measurement accuracy, the MAPE is 2,29, MAD is 2 and MSD is 5,54. Based on the visualization of the image, it can also be explained that several cases of empirical data still have a large distance from the expected model (LTM) so that this model is not the most appropriate model for this case. The next test is the Quadratic Trend Model (QTM). The following presents the findings of the second model test.

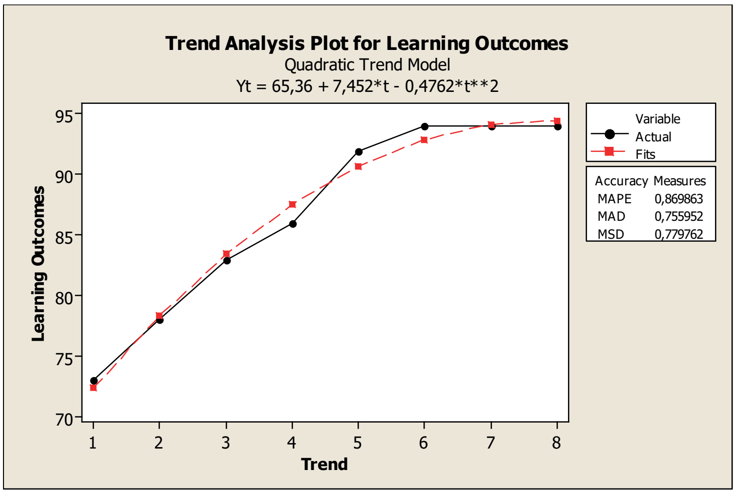

Figure 7. Analysis Results with Quadratic Trend Model

Figure 7 shows the trend of student learning outcomes after learning with AI integration in VR-based learning based on QTM. From these findings, some information can be explained, namely the black line shows empirical data in the form of student learning outcome trends from the field, while the red line shows the expected model based on the Quadratic Trend Model (QTM). When viewed from the measurement accuracy, the MAPE is 0,86, MAD is 0,75 and MSD is 0,77. Based on the visualization of the image, it can also be explained that the empirical data is still quite close to the expected model (QTM) so that this model has the potential to be the most appropriate model for this case. The next test is the Growth Curve Model (GCM). The following presents the findings of the second model test.

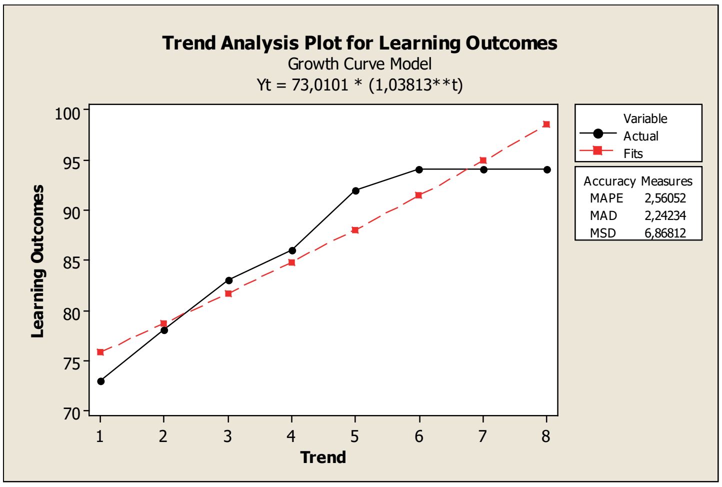

Figure 8. Analysis results with Growth Curve Model

Figure 8 shows the trend of student learning outcomes after learning with AI integration in VR-based learning based on GCM. From these findings, several pieces of information can be explained, namely the black line shows empirical data in the form of student learning outcome trends from the field, while the red line shows the expected model based on the Growth Curve Model (GCM). When viewed from the measurement accuracy, the MAPE is 2,56, the MAD is 2,24 and the MSD is 6,86. Based on the visualization of the image, it can also be explained that several cases of empirical data still have a large distance from the expected model (GCM) so that this model is not the most appropriate model for this case. The next test is the S-Curve Trend Model (SCTM). The following presents the findings of the second model test.

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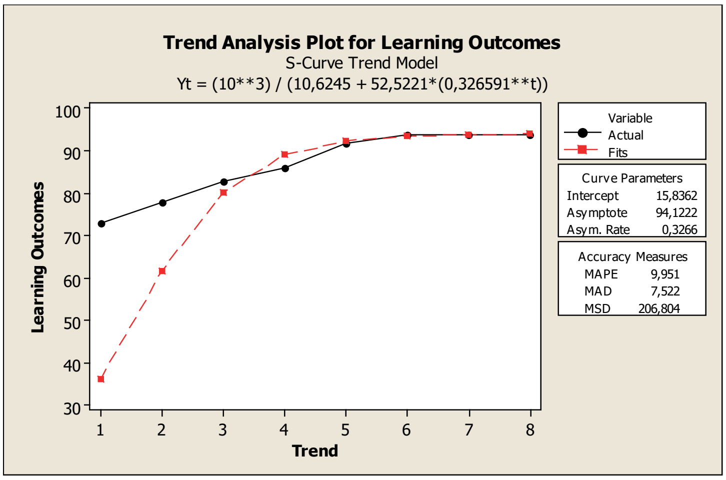

Figure 9. Analysis Results with S-Curve Trend Model

Figure 9 shows the trend of student learning outcomes after learning with AI integration in VR-based learning based on SCTM. From these findings, some information can be explained, namely the black line shows empirical data in the form of student learning outcome trends from the field, while the red line shows the expected model based on the S-Curve Trend Model (SCTM). When viewed from the measurement accuracy, the MAPE is 9,95, the MAD is 7,52 and the MSD is 206,8. Based on the visualization of the image, it can also be explained that several cases of empirical data still have a large distance from the expected model (GCM) so that this model is not the most appropriate model for this case.

Based on the results of the analysis of the four trend models tested, it was found that there was a positive trend in student learning outcomes in the integration of AI in VR-based learning. This is indicated by the graph of student learning outcomes which shows an increase based on the time series implemented in this study. Therefore, the integration of AI in VR-based learning has a positive effect on student learning outcomes. Further studies are related to the accuracy of the measurement model. The previous stage has determined that there are four models tested, namely: LTM, QTM, GCM and SCTM. The following table 1 presents the results of model testing to identify measurement accuracy against empirical data that has been obtained in the field.

Table 1. Recapitulation of The Four Models Tested

Models	Error Estimation		
	MAPE	MAD	MSD
LTM	2,29093	2	5,54167
QTM	0,869863	0,755952	0,779762
GCM	2,56052	2,24234	6,86812
SCTM	9,951	7,522	206,804

Table 1 shows a recapitulation of the results of the model accuracy test in terms of Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD), and Mean Squared Deviation (MSD). The most recommended model is the model with the smallest error. Based on this, it can be determined that the most recommended model for measuring the effectiveness of AI integration in VR-based learning is the Quadratic Trend Model (QTM).

DISCUSSION

Integration of technology in learning has become an urgent need in today's digital era. Technological advances have not only changed the way we communicate and work, but also the way students learn. By utilizing technology optimally, the learning process can be more effective, relevant, and interesting for students. This was found in this study with VR-based learning making students more active in learning the material. This finding is in line with previous findings which explained that VR allows students to engage deeply with educational content, allowing them to visualize and interact with complex concepts.[32,33,34,35,36] This situation has an impact on student motivation and learning satisfaction which increases because of its immersive nature[37] so that it is very suitable for developing students' critical thinking skills[38] and analytical skills.[39,40,41,42,43]

The empirical findings of this study clearly show that student learning outcomes have increased. When viewed from the VR aspect, this finding is relevant to previous research which explains that VR has been used to strengthen students' analytical skills[44] thereby improving their performance in learning.[45,46,47,48,49] In the context of this research, one of the materials taught is the traces of historical relics from the past related to various locations that must be visited. This can be overcome with VR where students can feel various traces of history without having to visit the location directly, only with a virtual visit[50] so that it can increase empathy, understanding of history[51] and cultural context effectively.[52]

This study has also proven that AI integration has a positive contribution to students' understanding and learning outcomes. AI is revolutionizing education by enabling personalized learning experiences tailored to individual student needs, abilities, and learning paces. AI systems can analyze student performance data to customize learning materials, ensuring that struggling students receive additional practice while those who grasp concepts quickly are presented with more challenging tasks. This adaptability not only enhances engagement but also promotes deeper understanding and retention of knowledge.

Personalized learning through AI is exemplified by platforms that utilize algorithms to assess student responses and provide immediate feedback. For instance, AI-powered assessment tools leverage natural language processing and deep learning to deliver real-time evaluations of assignments, allowing students to identify and correct mistakes promptly.[53] This immediate feedback mechanism is crucial for fostering a growth mindset, as it encourages students to learn from their errors and improve continuously.[54,55,56,57,58] Moreover, the integration of adaptive learning technologies allows for the creation of individualized learning paths that cater to various learning styles, such as visual, auditory, or kinesthetic preferences.[59,60]

The concept of adaptive learning is further supported by research indicating that personalized learning environments (PLEs) can significantly enhance student engagement and performance. These environments are designed to empower learners by providing content that aligns with their unique learning styles and backgrounds.[61] For example, AI systems can dynamically adjust the difficulty level of tasks based on real-time assessments of student capabilities, ensuring that each learner is appropriately challenged.[62] This adaptability is particularly beneficial in diverse classrooms where students may have varying levels of prior knowledge and learning preferences.[62]

Additionally, the role of AI in education extends beyond mere content delivery; it encompasses the development of comprehensive feedback systems that enhance learning outcomes. Automated feedback tools, as highlighted by Tubino and Adachi, can support students in developing feedback literacy, which is essential for academic success.[63] By automating low-level feedback, educators can focus on providing more complex, high-order thinking skills, thereby enriching the learning experience.[64] This dual approach of personalized content and constructive feedback creates a robust educational framework that fosters both immediate learning and long-term academic growth.

The research findings indicate that the Quadratic Trend Model is an effective measurement model, in line with previous studies that emphasize the importance of minimizing measurement error. Models that exhibit lower errors are generally preferred, as they indicate a better fit between the model and empirical data.[64,65] Flexibility in model structure does not always equate to empirical data conditions so careful consideration of statistical metrics is essential in model selection[66] to assess how well the theoretical model fits the observed data.[67,68]

The findings confirm that the Quadratic Trend Model stands out as the best measurement model due to its minimized measurement error and strong correspondence with empirical data. This conclusion is supported by a robust statistical criteria framework that collectively validates the model's effectiveness in capturing the complexity of the data on the effectiveness of AI integration in VR-based learning in elementary schools.

In conclusion, AI's capacity to personalize learning experiences, provide real-time feedback, and adapt to individual learning styles positions it as a transformative force in education. This contributes to strengthening students' learning experiences and understanding more effectively, leading to improved learning outcomes in line with the goals to be achieved. By leveraging these technologies, educators can create more engaging, effective, and inclusive learning environments that cater to the diverse needs of all students.

CONCLUSIONS

The integration of artificial intelligence into virtual reality-based learning environments offers transformative opportunities for elementary school learning. This study highlights the effects of AI-VR platforms to increase engagement, personalize learning experiences, and improve student learning outcomes over time. Through the Quadratic Trend Model (QTM), it is concluded that the integration of AI in VR-based learning shows a positive trend in terms of student learning outcomes.

By leveraging AI-driven insights, students can better understand the material and adjust the way to meet their needs, thereby encouraging a more inclusive and effective learning process. Furthermore, the immersive nature of VR, combined with the adaptability of AI, provides a unique medium to foster curiosity, critical thinking, and problem-solving skills in students.

This time series study underscores the need for continued research to optimize AI-VR integration and maximize its educational benefits while ensuring equitable access for all students. Future efforts should focus on scalability and sustainable models for broad adoption, ensuring that this technology can transform elementary education for diverse learning contexts.

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CONFLICT OF INTEREST
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