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Development of Virtual Reality–Based Learning Media on Particle Motion Dynamics Using the Kuula Platform Supported by a Digital Flipbook to Improve Conceptual Understanding of Senior High School Grade XI Students

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Abstract

Background: Innovative learning media are needed to address students' difficulties in understanding abstract physics concepts, particularly Particle Motion Dynamics, especially in schools with limited laboratory facilities.
Aims: This study aimed to develop Virtual Reality (VR) learning media based on 360° videos using the Kuula platform supported by a digital flipbook and to examine its validity, practicality, and effectiveness in improving senior high school students' conceptual understanding.
Methods: This study used a Research and Development (R&D) approach with the ADDIE model. The effectiveness of the product was tested using a one-group pretest–posttest design involving 40 Grade XI students at SMA Negeri 4 Bengkulu City. The product was validated by two physics lecturers and one physics teacher. Data were collected using validation sheets, student response questionnaires, and a conceptual understanding test. Data analysis included the Shapiro–Wilk test for normality, followed by the Wilcoxon signed-rank test to determine differences between pretest and posttest scores. Effect size was also calculated to measure the magnitude of the treatment effect.
Results: Expert validation showed an average feasibility score of 97, categorized as "very feasible". Students' responses were highly positive, with a score of 97 ("very good"). The N-Gain analysis indicated a significant improvement in conceptual understanding, with the average score increasing from 29 (pretest) to 93 (posttest), categorized as high improvement.
Conclusion: The Kuula platform–based VR learning media supported by a digital flipbook was valid, received positive responses from students, and effectively improved students' conceptual understanding of Particle Motion Dynamics. Therefore, it is feasible to be used as an alternative medium for physics learning.

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INTRODUCTION

To develop high-quality human resources, education is crucial. It is not only a process of transmitting knowledge; it is also a platform for cultivating character, skills, and attitudes necessary to deal with professional challenges and social demands. Within the framework of national development, education is widely recognized as a long-term investment that plays an essential role in enhancing both the quality of life and the competitiveness of a nation (Wahyuni & Kartika, 2021; Aliva & Ilhamsyah, 2021). The advancement of educational quality depends on ongoing innovation in both instructional strategies and the use of learning media that reflect contemporary trends. Moreover, successful learning is shaped not solely by teachers' competence, but also by the provision of sufficient facilities and the effective use of instructional media to support the overall teaching and learning process (Gunawan et al., 2023).

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In the twenty-first century, the demands placed on education have grown more complex, requiring students not only to understand conceptual knowledge but also to develop higher-order skills such as critical thinking, digital literacy, creativity, and problem-solving. The rapid advancement of information technology, along with the influence of globalization, has reshaped how learners access and interpret knowledge, thereby calling for learning environments that are more adaptive, interactive, and student-centered (Prihatini & Sugiarti, 2022; Puri et al., 2022). This situation requires teachers to integrate technology into the learning process in order to create more meaningful learning experiences. Among the various technological innovations, Virtual Reality (VR) has significant potential to be applied to education. VR allows students to engage with immersive three-dimensional virtual environments that simulate real-world situations, enabling abstract concepts to be represented in a more concrete and understandable form (Zhao et al., 2020; Ryan et al., 2022). A growing body of research indicates that the integration of VR in learning environments can improve students' motivation, increase their level of engagement, and strengthen their conceptual understanding (Saputro et al., 2023; Setyawati & Putra, 2021; Efendi et al., 2023). However, the application of VR in educational settings still encounters several obstacles. These challenges include inadequate infrastructure, limited technological literacy among teachers, and the complexity involved in developing VR-based learning media, which often requires specialized skills and expertise.

In line with these technological developments, various VR platforms have been designed to be more accessible and user-friendly, one of which is the Kuula. As a web-based platform, Kuula allows users to create and share interactive virtual content using 360-degree images or videos. Its ease of use and minimal hardware requirements make it a practical option for integration into school learning environments (Tserklevych et al., 2021; Daurrohmah, 2023). Several studies have indicated that open and easily accessible VR platforms can help broaden the adoption of VR technology in education (Rachmadtullah et al., 2023; Stevens et al., 2024). However, the utilization of Kuula as a learning medium in physics education remains very limited. Although numerous studies have explored the use of 360-degree video–based VR in learning, most of them focus on VR as a medium for passive observation or environmental visualization. This study introduces novelty in terms of learning media design and integration, where 360-degree VR videos are not only used for virtual environment exploration but are developed contextually and systematically in accordance with the physics learning sequence. The developed VR media includes a virtual tour of the Physics Laboratory of FKIP Universitas Bengkulu and 360-degree videos of Newton's law practicum demonstrations conducted by the researchers. Through this experience, students gain insights into laboratory procedures, force and motion concepts, and physical phenomena observed directly within a virtual environment.

Following the VR-based practicum demonstrations, students are guided to carry out independent activities using PhET simulations. This stage allows them to engage in interactive virtual experiments, manipulate variables, and examine the quantitative relationships between force, mass, and acceleration. In this approach, VR functions as an initial medium to introduce concepts in a contextual manner, while PhET supports active exploration and strengthens conceptual understanding. To complement these activities, all learning components are integrated into a digital flipbook, which presents theoretical content that cannot be fully addressed through practicum alone, particularly for Newton's Second and Third Laws. The flipbook includes conceptual explanations, contextual examples, embedded YouTube learning videos, and evaluation quizzes at the end of each section. The combination of 360-degree VR videos, PhET simulations, and digital flipbooks is designed to provide a structured and comprehensive learning experience that enhances students' understanding of Particle Motion Dynamics. Unlike standalone VR, which primarily emphasizes immersive visualization, this integrated approach offers a more holistic instructional design. While VR through Kuula provides contextual immersion, PhET enables experimentation and variable manipulation, and the digital flipbook delivers systematic conceptual reinforcement. As a result, students are not only able to observe phenomena but also analyze, experiment, and reflect on underlying concepts, leading to deeper conceptual understanding.

In physics learning, particularly in Particle Dynamics topics, students often experience difficulties in understanding abstract concepts such as force, motion, and interactions between objects (Radjawane et al., 2022). This material requires strong visualization skills and conceptual understanding, which are difficult to achieve when learning relies solely on verbal explanations or static media (Lolita et al., 2020; Agustin et al., 2021). The limited availability of laboratory facilities, along with the minimal implementation of practicum activities, has contributed to students' learning difficulties. Drawing on observations and interviews with both teachers and students at SMA Negeri 4 Bengkulu City, the physics laboratory is no longer used optimally and has been converted into classroom space. As a result, practicum-based learning is rarely conducted, and instruction tends to rely on lecture methods supported by simple presentation media. Students expressed that they find it difficult to understand physics concepts due to the lack of direct observation of physical phenomena. This situation reflects a mismatch between instructional needs and the supporting facilities available in the school.

This study employs the Problem-Based Learning (PBL) model due to its student-centered nature and focus on engaging learners in solving contextual, real-world problems. Through key stages such as problem orientation, independent investigation, collaborative discussion, and the presentation of findings, students are encouraged to actively construct their understanding and interpret concepts based on their own learning experiences. This approach aligns with the study's objective of improving students' conceptual understanding of physics, as it requires them to interpret, exemplify, classify, infer, compare, and explain the concepts being studied. In addition, PBL has been widely recognized for its effectiveness in fostering critical thinking and problem-solving abilities, which are crucial for understanding Newton's laws in Particle Motion Dynamics. Previous research also indicates that the application of PBL in physics learning contributes positively to students' conceptual understanding and overall learning outcomes (Rahmasiwi et al., 2023). Based on these considerations, the implementation of the PBL model in this study is deemed appropriate, as it complements the characteristics of Virtual Reality–based media and digital flipbooks that encourage active student involvement in exploring and applying concepts to real-life contexts. In this framework, PBL functions as a pedagogical approach that maximizes the potential of VR in supporting conceptual understanding. While VR offers immersive visualization of abstract physics phenomena, PBL organizes the learning process through stages such as problem identification, investigation, analysis, and solution development. By situating VR experiences within problem-based contexts, students are not limited to passive observation but are actively engaged in inquiry and conceptual reasoning. Consequently, VR is utilized not merely as a visualization tool, but as a medium that facilitates deeper cognitive engagement and meaningful construction of concepts.

Previous research in science and physics education has shown that the integration of VR can effectively improve students' conceptual understanding while also increasing their engagement in the learning process. Chien et al. (2020) reported that VR-based learning can improve student engagement, while Xiao et al. (2023) indicated that the use of VR can strengthen students' visualization abilities and foster creativity. Within physics education, VR is also recognized as an effective tool for facilitating conceptual understanding while offering a safe and well-controlled learning environment (Lie et al., 2022; Siahaan et al., 2023). However, a bibliometric analysis conducted using VOSviewer indicates that research integrating VR with the Kuula platform, particularly in the context of Particle Dynamics, is still relatively scarce (Ginting et al., 2023; Rizal et al., 2025). In addition to the use of VR, supporting media such as digital flipbooks also play a significant role in the learning process. Digital flipbooks allow instructional materials to be presented systematically through the integration of text, images, and multimedia elements, which can support students in understanding theoretical concepts both before and after engaging in VR-based learning experiences (Kaniawati et al., 2023; Aliyah & Istiqfaroh, 2022). The integration of VR and digital flipbooks aligns with Bruner's theory of representation and Paivio's Dual Coding Theory, both of which highlight the importance of combining visual and verbal information in learning. In addition, Mayer's multimedia learning theory further supports the use of integrated media as a means to enhance and optimize students' cognitive processing.

However, most previous studies have tended to use VR as a standalone instructional tool without systematically integrating it with interactive simulations and structured digital learning materials within a unified pedagogical framework. In addition, research that combines Kuula-based 360-

degree VR, PhET simulations, and digital flipbooks in Particle Dynamics using a structured approach such as Problem-Based Learning remains limited. Therefore, this study seeks to develop and implement an integrated VR-based learning environment supported by PBL in order to enhance students' conceptual understanding of Particle Motion Dynamics. Specifically, this study aims to: (1) develop Virtual Reality–based learning media using 360-degree videos on the Kuula platform supported by digital flipbooks for Particle Dynamics material; (2) analyze the validity of the media based on assessments by two physics lecturers from Universitas Bengkulu and one senior high school physics teacher; (3) examine the responses of teachers and Grade XI D students of SMA Negeri 4 Bengkulu City toward the developed learning media; and (4) identify improvements in students' conceptual understanding after the use of the learning media based on conceptual understanding tests. This study is expected to contribute both theoretically and practically to the development of innovative, accessible physics learning media that are aligned with the Merdeka Curriculum.

RESEARCH METHODS

Research Type and Design

This study adopts a Research and Development (R&D) approach to produce VR–based learning media utilizing 360° video on the Kuula platform, complemented by a digital flipbook, for the Particle Dynamics topic in Grade XI senior high school. The development process follows the ADDIE model, which includes five stages: Analysis, Design, Development, Implementation, and Evaluation, as presented in Figure 1.

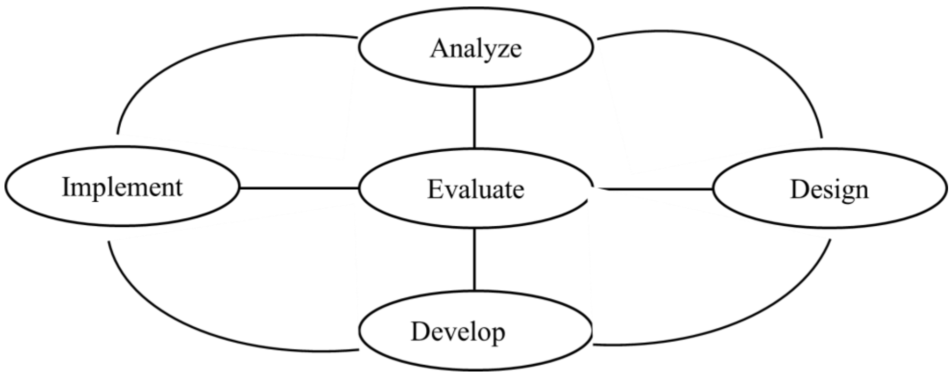

Figure 1. ADDIE Model Stages

(Wardani, 2020)

The development of the VR–based learning media using 360° video was designed in a systematic manner, starting with the creation of the main media in the form of virtual tour videos covering the route from the entrance gate to the FKIP laboratory, as well as 360° VR recordings of practicum activities on Particle Motion Dynamics (Newton's Laws) conducted in the laboratory using an Insta360 X3 camera. To support the delivery of learning content, the VR media was complemented by a digital flipbook as an additional instructional medium. During the design phase, the learning sequence was structured according to the syntax of the PBL model. The process began with the formulation of guiding questions aimed at directing students toward the problems presented. Learning materials were then organized within a digital flipbook containing conceptual explanations. In the investigation stage, the design incorporated 360° VR–based practicum videos on Newton's First Law, supplementary YouTube videos illustrating the application of Newton's Second and Third Laws, and integrated PhET Simulation links intended to be accessed after students have observed the practicum activities. The learning sequence concluded with the inclusion of practice problems designed to facilitate analysis and reinforce conceptual understanding. This overall design was employed to assess the enhancement of students' conceptual understanding after engaging with the developed learning media.

Research Subjects

The participants of this study were 40 students from Grade XI D at SMA Negeri 4 Bengkulu City. The validation process involved two physics lecturers from Universitas Bengkulu and one senior high school physics teacher, who acted as experts in subject matter, media, and instructional design.

Research Population

The population of this study included all Grade XI students at SMA Negeri 4 Bengkulu City. However, the implementation of the developed learning media was carried out through a limited trial involving one class, namely Grade XI D, as the research sample.

Research Instruments

The research instruments included: (1) expert validation sheets used to assess the feasibility of content, presentation, and media appearance; (2) teacher and student response questionnaires using a four-point Likert scale (scores 1–4) to evaluate the practicality of the learning media; and (3) a conceptual understanding test consisting of 10 multiple-choice items developed based on conceptual understanding indicators.

Research Procedures and Timeline

The development of the learning media followed the five phases of the ADDIE model: Analysis, Design, Development, Implementation, and Evaluation. In the analysis phase, learning needs were identified through observations, interviews with teachers and students, and documentation review. The design phase focused on structuring the learning media based on the integration of VR and digital flipbooks, as well as preparing the research instruments. During the development phase, 360° VR videos were produced using the Kuula platform, alongside the creation of digital flipbooks. The developed media were then validated by experts and revised according to their feedback. The implementation phase involved applying the media in physics learning with Grade XI D students at SMA Negeri 4 Bengkulu City. In this stage, students accessed the Kuula-based VR content using their personal smartphones via a web browser. Although access through laptops was also possible, smartphones were considered more practical as they did not require additional devices such as VR headsets or other specialized equipment, which highlights the accessibility of this approach in schools with limited technological resources. The evaluation phase was conducted to determine the quality of the developed media and to analyze improvements in students' conceptual understanding, based on validation results, user responses, and test outcomes. This study was carried out from 29 October to 30 November 2025 in the first term of the 2025-2026 school year.

Data Analysis Techniques

Data obtained from expert validation and teacher and student response questionnaires were analyzed using descriptive quantitative methods by calculating percentage scores based on a four-point Likert scale (1–4) to determine the levels of validity and practicality of the learning media. The effectiveness of the media was evaluated using the results of a conceptual understanding test consisting of 10 multiple-choice items, based on the scores of 40 Grade XI D students at SMA Negeri 4 Bengkulu City. The criteria for assessing media feasibility are presented in Table 1, student response criteria in Table 2, and the N-Gain index criteria used to measure improvements in students' conceptual understanding as an indicator of media effectiveness are shown in Table 3.

To determine the validity of the learning media, the scores obtained are explained using the following percentage score formula:

$$Validation\ Score\ Percentage = \frac{Obtained\ Score}{Total\ Score}\ x\ 100\% \tag{1}$$

Table 1 contains the criteria used to interpret these percentage scores.

Table 1. Validation Result Criteria

Percentage (%)	Category
0% - 25%	Not Feasible
26% - 50%	Less Feasible
51% – 75%	Feasible

Percentage (%)	Category
76% - 100%	Very Feasible

(Siahaan et al., 2019)

To examine teachers' and Grade XI D students' responses to the developed learning media at SMA Negeri 4 Bengkulu City, the obtained scores were analyzed using the percentage score formula as follows:

$$\%\ Score\ Interpretation = \frac{\sum Obtained\ Score}{Maximum\ Score}\ x\ 100\% \quad (2)$$

Next, the percentage score is calculated according to the criteria outlined in Table 2.

Table 2. Criteria for Student Response Assessment

Percentage (%)	Category
0% - 25%	Very Poor
26% - 50%	Poor
51% – 75%	Good
76% - 100%	Very Good

(Melianti et al., 2020)

Pretest and posttest scores were analyzed using the N-Gain index according to the following formula to determine whether students' conceptual understanding has increased after the application of learning media:

$$N - Gain = \frac{Postest\ Score}{Ideal\ Score} - \frac{Pretest\ Score}{Pretest\ Score}\ x\ 100\% \quad (3)$$

Next, the resulting score percentages are interpreted according to the criteria presented in Table 3.

Table *3.* Criteria for the N-Gain Index

N-Gain	Category
(g) ≥ 0,7	High
0,3 ≤ (g) < 0,7	Medium
(g) < 0,3	Low

(Ramdhani et al., 2020)

To determine whether the data are normally distributed, a normality test is performed using the Shapiro–Wilk test. In general, decisions about normality are made based on the significance value (p-value) with the following criteria:

$$W = \frac{\left(\sum_{i=1}^{n} a_i x_{(i)}\right)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (4)$$

The decision rule for the Shapiro–Wilk test is defined as follows:
If Sig. > 0.05, the data are considered normally distributed, and if Sig. ≤ 0.05, the data are considered non-normally distributed.

The Wilcoxon Signed Rank Test is used to test for differences between pretest and posttest scores. In most cases, the significance value (p-value) is used to make a decision:

$$Z = \frac{T - \mu_T}{\sigma_T} \quad (5)$$

With

$$\mu_T = \frac{n(n+1)}{4} \quad (6)$$

$$\sigma_T = \sqrt{\frac{n(n+1)(2n+1)}{24}} \quad (7)$$

Description:

T = smallest number of ranks

n = number of data pairs

The null hypothesis (H_o) is accepted if the significance value (p-value) is greater than 0.05, indicating that there is no significant difference between the pretest and posttest scores. Conversely, if the significance value (p-value) is less than or equal to 0.05, the null hypothesis (H_o) is rejected.

The effect size is calculated to determine how big the difference is between the pretest and posttest scores. The effect size (r) for the Wilcoxon Signed Rank Test can be calculated using the following formula:

$$r = \frac{Z}{\sqrt{n}} \quad (8)$$

Cohen's criteria state that an effect size of 0.20 indicates a small effect, 0.50 indicates a medium effect, and 0.80 or higher indicates a large effect.

This study is expected to objectively describe the validity, usefulness, and efficacy of Virtual Reality-based learning media using the Kuula platform, which is supported by digital flipbooks for learning Particle Dynamics in Grade XI, based on the data collection process and analysis techniques used.

Limitations

This study focused on the development and limited implementation of 360° video–based Virtual Reality learning media using the Kuula platform, supported by a digital flipbook, for the Particle Dynamics topic in Grade XI of senior high school. The trial was conducted in a single class at SMA Negeri 4 Bengkulu City; therefore, the results are confined to this context and are not intended to be generalized broadly.

RESULTS AND DISCUSSION

Results

This study produced a virtual reality–based physics learning medium utilizing the Kuula platform, complemented by a digital flipbook, for the topic of teaching particle motion dynamics at Grade XI senior high level. The developed media were subsequently evaluated through expert validation to determine their feasibility and appropriateness for use in physics learning. This validation stage is essential to ensure that the media meet the required standards before being implemented in instructional activities. In general, the feasibility assessment covers several aspects, including content, presentation, media design, and language, as commonly applied in previous studies on the development of technology-based learning media (Risdianto, 2020; Risdianto, 2022).

Expert validation was carried out to determine whether the developed media met the required standards in terms of both content and presentation quality. The results of this evaluation are presented in Table 4. The assessment encompassed several aspects, including content feasibility, material accuracy, presentation techniques, supporting elements, media design, and language use.

Table 4. Results of Expert Validation on Virtual Reality–Based Learning Media Using the Kuula Platform and Digital Flipbook

No	Assessed Aspect	Obtained Score	Maximum Score	Percentage	Category
1	Content Feasibility	36	36	100%	Very Feasible
2	Material Accuracy	35	36	97%	Very Feasible
3	Presentation Technique	24	24	100%	Very Feasible
4	Presentation Support	11	12	92%	Very Feasible
5	Media Aspect	69	72	96%	Very Feasible
6	Language Aspect	24	24	100%	Very Feasible
	Average	199	204	**97%**	**Very Feasible**

Students' responses to the learning media serve as an important indicator for evaluating its acceptability and potential effectiveness in the physics learning process. In physics education research, such responses are commonly used to describe students' attitudes, interests, and perceived ease of use of instructional media (Risdianto, 2022). The responses of 40 students from Grade XI D at SMA Negeri 4 Bengkulu City toward the Virtual Reality–based learning media using the Kuula platform, supported by a digital flipbook, are presented in Table 5. The evaluation was conducted using a four-point Likert scale questionnaire covering aspects of media appearance and material presentation.

Table 5. Students' Responses to Kuula-Based Virtual Reality Learning Media Assisted by a Digital Flipbook

No	Assessed Aspect	Obtained Score	Maximum Score	Percentage	Category
1	Media Appearance	630	640	98%	Very Good
2	Material Presentation	930	960	97%	Very Good
	Average	1560	1600	**97%**	**Very Good**

The effectiveness of the Virtual Reality–based learning media using the Kuula platform, supported by a digital flipbook, was evaluated using the N-Gain analysis, and the results are presented in Figure 2.

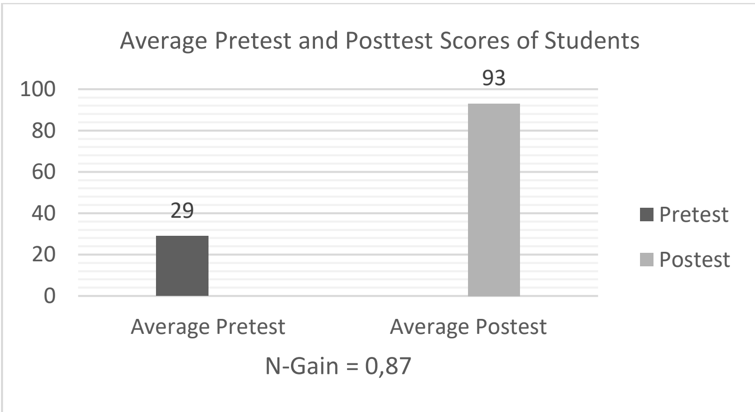

Figure 2. Average Pretest and Posttest Scores of Students According to N-Gain Analysis

Improvements in students' conceptual understanding were further analyzed for each indicator. Pretest and posttest scores were examined based on the items representing each indicator, where indicators with more than one item were calculated using the average score, while those represented by a single item used the corresponding score. The N-Gain value for each indicator was then determined to classify the level of improvement in students' conceptual understanding, as presented in Table 6.

Table 6. N-Gain Values of Students' Conceptual Understanding by Indicator

Question Number	Ability Indicators	Pretest Score	Posttest Score	N-Gain	Category
1,4,10	Interpreting	16.01	62.82	0.56	Medium
2,7	Giving Examples	33.75	93.75	0.91	High
3,8	Explaining	31.25	100	1.00	High
5	Classifying	35	95	0.92	High
6	Drawing Inferences	12.5	90	0.89	High
9	Comparing	10	75	0.72	High

To determine whether the data were normally distributed, tests for normalcy were performed using the Kolmogorov–Smirnov and Shapiro–Wilk methods. The results are presented in Table 7.

Table 7. Results of the Kolmogorov-Smirnov and Shapiro-Wilk Normality Tests

	Kolmogorov-Smirnov Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Pretest	0.226	40	< 0.001	0.922	40	0.009
Posttest	0.273	40	< 0.001	0.770	40	< 0.001

To examine the difference between pretest and posttest scores, the Wilcoxon Signed Ranks Test was conducted. The results are shown in Table 8.

Table 8. Wilcoxon Signed Ranks Test Results (Posttest – Pretest)

Test Statistics	Value
Z	-5.543
Asymp. Sig. (2-tailed)	< 0.001

The magnitude of the treatment effect was calculated using Cohen's d. The results are presented in Table 9.

Table 9. Effect Size of the Implementation

Cohort	Cohen's d	Effect Category
Dynamics of Particle Motion	0.876	Large

Discussion

Interpretation of Research Results

The VR–based learning media utilizing 360° video on the Kuula platform, supported by a digital flipbook, for the Particle Dynamics topic was developed through a series of research and development stages, including needs analysis, media design, product development, expert validation, revision, and limited trials involving 40 Grade XI D students at SMA Negeri 4 Bengkulu. The resulting media were specifically designed to address the constraints of laboratory facilities and to support the implementation of laboratory activities, which are rarely conducted in the learning process.

Based on expert validation results presented in Table 4, the VR–based physics learning media utilizing 360° video on the Kuula platform, supported by a digital flipbook, was categorized as highly feasible for teaching Particle Dynamics to Grade XI students. The evaluators' assessments showed that the developed media met all feasibility criteria, including content validity, material accuracy, presentation techniques, supporting elements, media design, and language use. This finding indicated that the media are not only technically appropriate but also meet the essential requirements for both material quality and instructional presentation for high school physics learning. From the perspective of content and material accuracy, the media effectively present Particle Dynamics concepts in accordance with the basic competencies and learning objectives of the Merdeka Curriculum. The material is organized in a structured and conceptually coherent manner, enabling students to gradually construct their understanding of physics concepts. Furthermore, the virtual learning environment allows students to observe physical phenomena more concretely, which is consistent with Radianti et al. (2020), who argue that VR technology can enhance conceptual understanding through immersive learning experiences.

The presentation and supporting elements indicate that the developed media are well-structured, interactive, and easy to use. The learning content is not limited to textual explanations but is enriched with 360° laboratory demonstration videos and integrated digital flipbooks that help strengthen students' conceptual understanding. Such an approach promotes meaningful learning, as students are not merely receiving information but actively constructing knowledge through interaction with the virtual environment. These findings are consistent with Makransky et al. (2021), who suggest that VR-based learning environments can enhance cognitive engagement and support deeper knowledge construction.

In terms of media aspects, the visual design, navigation, and level of interactivity were found to effectively support the learning process. The use of virtual space visualization enables students to experience learning in a way that closely resembles direct observation of physical phenomena, thereby helping to reduce potential misconceptions. This finding is in line with Yin et al. (2022), who highlight that VR media are effective in visualizing scientific concepts that are difficult to observe in real-world settings. From a language perspective, the media employ clear and communicative language that adheres to standard Indonesian grammar and is appropriate to the cognitive level of Grade XI students. The use of physics terminology is consistent and easily understood, which helps minimize misinterpretation of concepts. Overall, the expert validation results demonstrate that the VR-based learning media using the Kuula platform and digital flipbooks meet comprehensive feasibility criteria, with particular strengths in visualization, interactivity, and systematic presentation. These findings indicate that the developed media are comparable to, and potentially more effective than, previously reported interactive digital media, especially in the context of web-based VR applications for high school physics learning.

After being validated by experts, the VR-based learning media using the Kuula platform and digital flipbook were implemented with 40 Grade XI D students to evaluate their practicality based on user responses. The results, presented in Table 5, indicate that students showed highly positive responses toward the developed media. This is reflected in the assessment of media appearance and material presentation, which achieved an average score of 97%. These findings suggest that the media are not only feasible in terms of content but also practical and easy to use in physics learning. This result is consistent with previous studies by Saputro et al. (2023) and Setyawati & Putra (2021), which report that the use of VR in physics learning can enhance student engagement, motivation, and conceptual understanding. In addition, Efendi et al. (2023) highlight that VR-based visualization supports the creation of more interactive and meaningful learning experiences. Therefore, the highly positive responses obtained in this study demonstrate that the incorporation of Kuula-based VR and digital flipbooks is capable of providing a learning environment that aligns with the demands of 21st-century learning, particularly in terms of interactivity and accessibility.

The improvement in students' conceptual understanding after the implementation of the VR-based learning media utilizing 360° video on the Kuula platform and a digital flipbook was evaluated using the N-Gain analysis. The results show a clear increase in students' scores from pretest to posttest, as presented in Table 6, indicating the effectiveness of the developed media in improving conceptual understanding of Particle Dynamics. Further analysis based on individual cognitive indicators, as shown in Table 7, reveals improvements across all measured aspects, including interpreting, exemplifying, explaining, classifying, inferring, and comparing. Most indicators demonstrate a high level of improvement, while the interpreting indicator falls within the moderate category. These data suggest that the implemented learning approach improves students' quantitative achievement as well as the overall quality of their conceptual understanding.

Normality tests were used to examine data distribution using the Kolmogorov–Smirnov and Shapiro–Wilk methods, and the results are shown in Table 7. The findings indicate that the data were not normally distributed; therefore, a non-parametric approach was applied for further analysis. Differences between pretest and posttest scores were examined using the Wilcoxon Signed-Ranks Test, as shown in Table 8. The results show a statistically significant difference in the two sets of scores, indicating that the implementation led to a meaningful improvement in students' learning outcomes. In addition, the effect size was calculated using Cohen's d, and the results presented in Table 9 show that it fell within the large category. This suggests that the implementation had a substantial and practically significant impact on students' understanding of Particle Motion Dynamics.

The improvement observed in the exemplifying and classifying indicators suggests that students were able to relate physics concepts to contextual situations and categorize phenomena based on relevant characteristics. Similarly, the increase in the inferring and comparing indicators indicates that students began to demonstrate reasoning skills, analyze relationships between concepts, and draw conclusions from the information obtained during the learning process. However, the interpreting indicator showed only a moderate level of improvement, indicating that students' ability to interpret physics concepts still requires further reinforcement. This may be attributed to the higher-order cognitive demands of interpretation, which involve connecting multiple representations, analyzing relationships between variables, and translating visual information into abstract conceptual explanations. Although the VR environment provides rich and immersive visualizations, some students may still require additional guidance to effectively transform these experiences into deeper conceptual understanding. Therefore, future implementations should incorporate more structured scaffolding, such as guiding questions, reflective discussions, and interpretation-focused tasks that explicitly train students to explain the meaning of observed phenomena. Through these strategies, VR-based learning environments can more effectively support the development of students' interpretation skills in physics. Overall, the findings indicate that the use of VR-based learning media through the Kuula platform has a positive impact on students' conceptual understanding. This is consistent with Piaget's constructivist theory, which posits that students at the high school level are in the formal operational stage, where concept formation is enhanced when learners first engage with concrete visual experiences before progressing to abstract reasoning. In this context, Kuula-based VR media provide interactive visual experiences that help support the development of more robust and meaningful cognitive schemas.

These findings are in line with previous studies by Lie et al. (2022) and Siahaan et al. (2023), which report that Virtual Reality–based learning can improve students' conceptual understanding and visualization skills, particularly in abstract physics topics. Therefore, the consistent improvement observed across all indicators of conceptual understanding suggests that the integration of Kuula-based VR media and digital flipbooks is effective in enhancing the overall quality of students' conceptual understanding.

Learning media link: https://heyzine.com/flip-book/cbee631031.html

Figure 3. Flipbook Media Interface

Figure 3 presents the interface of the digital flipbook used as a supporting medium in teaching Particle Dynamics. The flipbook is systematically organized in accordance with the learning objectives and includes the title, learning objectives, a virtual tour of Universitas Bengkulu, a table of contents, conceptual explanations, 360° video–based practicum demonstrations, example problems, visual illustrations, and a summary of the material. The digital flipbook serves as a tool for reinforcing conceptual understanding both before and after students engage with the Virtual Reality media. In this way, students not only gain immersive visual experiences but also develop a clear conceptual foundation for understanding the material. Furthermore, the flipbook format enables students to learn independently in a structured manner, facilitating the connection between virtual visualizations and the mathematical as well as conceptual representations in physics.

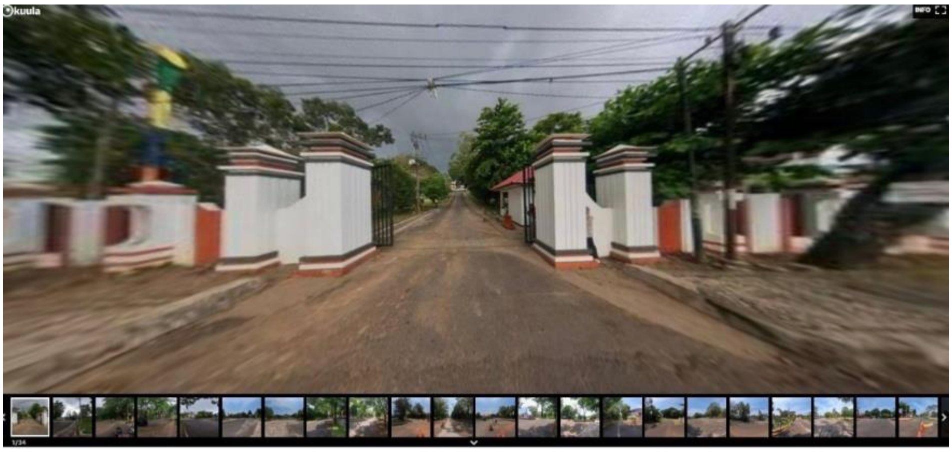

Figure 4. Kuula Interface Supporting 360° VR Video Media

Figure 4 displays the interface of the Kuula platform, which is used to host and present 360° video visualizations for the Particle Dynamics topic. The platform is designed to create an immersive learning experience by enabling students to explore virtual environments, allowing them to observe motion, forces, and object interactions in a more concrete manner. The media can be easily accessed through mobile devices without the need for specialized equipment, making it practical for use in schools with limited laboratory facilities. Through interaction with the virtual environment, students are encouraged to explore and observe independently, which supports the development of their conceptual understanding of abstract physics concepts.

Comparison with Previous Studies

These results are in agreement with previous studies by Zhao et al. (2020), Setyawati & Putra (2021), and Saputro et al. (2023), which highlight that the use of VR in physics learning can enhance both students' conceptual understanding and engagement. They also support the findings of Lie et al. (2022) and Siahaan et al. (2023), who emphasize the effectiveness of VR in visualizing abstract physics phenomena. The novelty of this study lies in the use of the Kuula platform, which has been relatively underexplored in educational VR research, thereby offering new insights into the application of web-based VR technologies in physics learning.

Implications

Theoretically, this study reinforces Paivio's Dual Coding Theory, Bruner's Representation Theory, and Mayer's Multimedia Learning Theory, which emphasize the importance of integrating visual and verbal information to enhance students' cognitive processes. Practically, the findings indicate that VR-based media supported by Kuula and digital flipbooks can serve as an alternative solution for physics learning in schools with limited laboratory facilities.

Research Contributions

This study contributes to the advancement of VR-based physics learning media through the use of the Kuula platform, which is relatively accessible and compatible with the implementation of the Merdeka Curriculum. The results provide empirical evidence that integrating VR media with digital flipbooks can effectively improve students' conceptual understanding of Particle Dynamics. In addition, this research expands the body of scientific literature regarding the use of web-based VR platforms in senior high school physics learning, particularly for topics that involve the visualization of abstract concepts.

Limitations

This study has several limitations. The implementation was carried out in only one class, XI D at SMA Negeri 4 Kota Bengkulu, which involved 40 students and focused on a single topic, namely Particle Dynamics. Furthermore, the study did not include a comparison group (control class), therefore the findings cannot yet be generalized to a wider context of physics learning.

Suggestions

Considering these limitations, future studies are suggested to develop Virtual Reality–based learning media using the Kuula platform for other physics topics and to conduct broader trials that include a control group for comparison. Further research may also investigate the influence of VR-based media on students' higher-order thinking skills (HOTS) and scientific attitudes in order to expand the understanding of the potential impacts of this learning approach.

CONCLUSION

Based on the research findings and discussion, it can be concluded that this study successfully developed VR–based learning media using the Kuula platform supported by digital flipbooks for the Particle Dynamics topic for eleventh-grade high school students through the ADDIE development model, which includes the analysis, design, development, implementation, and evaluation stages. The developed media contains 360° videos, interactive navigation, and digital flipbooks for concept reinforcement, resulting in a learning media product that is ready for use in physics instruction. The learning media were deemed highly feasible based on expert validation, achieving the "very feasible" category across all assessment aspects. This indicates that the media meets the standards of feasibility in terms of content, presentation, media, and language. The Kuula-based VR learning media supported by digital flipbooks was also considered practical for classroom use. Student responses fell into the "very good" category, indicating that the media is easy to use, engaging, and aligns with students' learning characteristics. Furthermore, the developed media proved effective in enhancing students' conceptual understanding of Particle Dynamics. The N-Gain analysis results were in the high category, and improvements occurred across all conceptual understanding indicators, demonstrating that the media can comprehensively improve students' conceptual mastery. Therefore, the Kuula-based VR learning media supported by digital flipbooks is considered feasible, practical, and effective as an alternative physics learning medium for eleventh-grade high school students.

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AUTHOR CONTRIBUTION STATEMENT

The contributions of each author in this study are as follows: PWR was responsible for the conceptualization of the research, data collection, media development, data analysis, and preparation of the initial manuscript draft. ER contributed through supervision, methodological validation, and reviewing and editing the manuscript. AP provided input focusing on the design stage and the analysis of research results.

AI DISCLOSURE STATEMENT

During the preparation of this manuscript, the authors utilized ChatGPT to assist in identifying relevant keywords prior to conducting a bibliometric analysis using Scopus, Bibliometrix, and VOSviewer. These tools were employed to map research trends, identify potential research gaps, and explore novelty within the field of study. Additionally, Scite AI was used to help locate relevant scholarly sources for developing the research background. Following the use of these tools, the authors carefully reviewed, verified, and edited all generated content to ensure its accuracy, originality, and adherence to academic standards. The authors assume full responsibility for the interpretation, integrity, and content of the final published manuscript.

CONFLICTS OF INTEREST

The authors state the absence of any financial, institutional, or personal conflicts of interest that may have influenced any stage of this study, including its implementation, data analysis, manuscript development, or publication decisions.

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