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Research Article

ENHANCING CRITICAL THINKING SKILLS THROUGH ANDROID-ASSISTED VIRTUAL PHYSICS LEARNING: A FOCUS ON HOTS DEVELOPMENT

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Abstract
This study investigates the effectiveness of Android-assisted virtual physics learning developed using *Smart Application Creator* in enhancing students' critical thinking skills during the study of optical material in high school. The novelty of this research lies in its integration of mobile-based virtual learning environments with a targeted emphasis on Higher Order Thinking Skills (HOTS) a crucial competency in 21st-century education. While prior studies have explored virtual learning media in science education, few have systematically examined their cognitive impact particularly on critical thinking in the context of physics. A quasi-experimental design with a nonequivalent control group was used, and purposive sampling determined the participant pool. Data were collected using validated test instruments designed to assess five core indicators of critical thinking. Statistical analysis through an independent sample t-test at a significance level of α = 0.05 revealed a sig. (2-tailed) value of 0.00, indicating a significant difference between the experimental and control groups. The average N-Gain in the experimental group (0.74) significantly outperformed that of the control group (0.53). The most notable improvements in the experimental group included the ability to evaluate arguments (88.2%), draw conclusions (84.3%), identify assumptions (80.4%), apply deductive reasoning (75.2%), and logically interpret data (65%). These findings demonstrate the pedagogical potential of Android-based virtual media in supporting cognitive development in physics learning. The study provides a foundation for developing scalable, interactive learning tools that align with HOTS frameworks, offering new directions for physics instruction in digitally driven classrooms.

Keywords: Android-Assisted, Critical Thinking Skills, Effectiveness, Physics Mobile Learning, Physics HOTS, Virtual

INTRODUCTION

Education serves as a deliberate, systematic, and dynamic endeavor aimed at nurturing human potential across cognitive, affective, and psychomotor domains. It facilitates the holistic development of students cultivating their spirituality, intellectual acuity, moral integrity, personal autonomy, and social responsibility to navigate personal, national, and global challenges. As Ichsan (2016) affirms, education is a purposeful activity designed to equip individuals with relevant knowledge, skills, and adaptive behaviors. Similarly, Erica et al. (2019) describe education as a structured, goal-oriented process wherein instructional interaction between teachers and students plays a central role in enhancing human capital. Synthesizing these perspectives, education emerges as a reciprocal, dialogic process aimed at unlocking students' latent capabilities through effective pedagogical design.

In the 21st century, education faces a pivotal demand: the need to develop students' Higher Order Thinking Skills (HOTS), particularly critical thinking a fundamental component of modern cognitive development and a key marker of educational quality (Shanti et al., 2017). Nowhere is this need more apparent than in Physics education, a discipline that not only imparts conceptual knowledge but also fosters analytical, logical, and evaluative skills essential for scientific inquiry. As Kartimi & Liliasari (2012) note, critical thinking in Physics education entails the ability to analyze problems, derive conclusions, and apply reasoning based on experiential evidence. To meet this challenge, educators must move beyond traditional didactic approaches and incorporate innovative strategies that actively engage students. One promising avenue is the integration of mobile learning technologies, particularly Android-based applications, which offer flexible, interactive, and personalized learning experiences. Mardiana & Kuswanto (2017) demonstrated that such platforms significantly enhance students' HOTS and divergent thinking by fostering immersive and dynamic engagement with Physics content.

Several empirical studies corroborate the effectiveness of technology-assisted learning in Physics. For instance, Festiyed et al. (2019) reported improvements in students' diagrammatic representation and critical reasoning skills through culturally integrated mobile learning tools. Ferty et al. (2019) found that technology simulations, when combined with scaffolding techniques, effectively promoted critical thinking by providing structured yet exploratory learning environments. Additionally, Herliandry et al. (2020) highlighted the potential of Physics Multimedia Learning (PsML) to enhance critical thinking in distance learning contexts, owing to its engaging, interactive content.

Similarly, multimedia learning tools have been found to improve problem-solving abilities (Manurung & Panggabean, 2020), with mobile applications offering considerable gains in students' conceptual understanding and cognitive engagement (Fauyan, 2019). Despite these promising outcomes, classroom observations from internships reveal a persistent gap: only 15% of students achieved the minimum competency criteria (KKM) on critical thinking questions, especially on optics-related content, despite full attendance. This suggests that many students continue to struggle with drawing conclusions, identifying assumptions, and applying logical reasoning—core indicators of critical thinking (Luzyawati, 2017).

Moreover, while existing literature supports the efficacy of mobile learning platforms, the majority of these studies are descriptive in nature, often confined to small-scale contexts with limited focus on subject-specific applications (George et al., 2012; Hingkua et al., 2014; Azis & Clefoto, 2024; Setiyani, Panomram, & Wangdi, 2024). The need for empirical, domain-specific investigations into how mobile learning platforms influence cognitive development especially in Physics remains underexplored.

While previous studies provide a general understanding of the benefits of mobile learning in education, three significant research gaps. Lack of subject-specific investigations: Most research offers generalized findings across disciplines, with insufficient focus on Physics-specific critical thinking skills, particularly in abstract or complex topics like optics. Limited integration of local wisdom: Although a few studies (e.g., Ferlianti et al., 2023) have examined the cultural contextualization of mobile learning, there is a lack of comprehensive analysis regarding how local cultural elements—when embedded in virtual learning tools—impact students' cognitive engagement and critical thinking development in Physics. Underdeveloped analysis of critical thinking dimensions: There is limited insight into which specific components of critical thinking (e.g., inference, argument evaluation, deductive reasoning) are most influenced by mobile learning interventions. A more granular investigation is needed to inform precise instructional design.

This research aims to examine the effectiveness of Android-based virtual learning platforms in enhancing critical thinking skills among high school students, with a particular focus on Physics education in the topic of optics. The study will Analyze the influence of virtual mobile learning on students' Physics HOTS. Investigate which dimensions of critical thinking are most improved through Android-supported Physics instruction. Evaluate the added value of integrating local wisdom into mobile learning tools to promote deeper conceptual understanding and cognitive engagement. By offering an empirical, context-specific analysis, this study contributes to the evolving field of educational technology and provides actionable recommendations for designing effective, culturally responsive mobile learning interventions in Physics education. Ultimately, the findings aim to support educators in transforming pedagogical approaches to foster 21st-century cognitive competencies not only in knowledge acquisition but also in thinking critically, solving problems, and adapting to complex realities in science and beyond.

RESEARCH METHOD

This study employed a quasi-experimental research design, specifically the Non-Equivalent Control Group Design, to evaluate the impact of Android-assisted virtual physics learning on students' critical thinking skills. The quasi-experimental design was chosen because it is well-suited for educational research conducted in real-world classroom settings, where random assignment of participants to experimental and control groups is often impractical or unethical. In this study, the researchers aimed to evaluate the effectiveness of Android-assisted virtual physics learning on students' critical thinking skills. Key reasons for selecting this design include: Practicality in Educational Settings, Quasi-experimental designs allow researchers to work with intact groups, such as existing classrooms, without disrupting the natural learning environment. This approach was appropriate since reorganizing students into randomized groups could have been disruptive to the school's schedule and learning dynamics. Ethical Considerations, Randomly assigning students to experimental and control groups might create unequal access to the intervention, which could raise fairness concerns. The quasi-experimental design respects the ethical obligation to provide similar educational opportunities to all students within the same school context. Comparative Analysis, By using the Non-Equivalent Control Group Design, the study can compare the outcomes between the experimental group (using Android-assisted learning) and the control group (using traditional methods), providing insights into the effectiveness of the intervention. Feasibility, Given the constraints of working within a school system, this design enables researchers to implement the study without needing to disrupt class structures or schedules. Enhanced Internal Validity, While randomization is absent, measures were taken to ensure internal validity, such as using pretests and posttests to compare groups and employing validated instruments to assess critical thinking skills. By selecting a quasi-experimental design, the study balances the need for methodological rigor with the practicalities and ethical considerations inherent in educational research. The research was conducted at a high school in North Sumatra Province during the first semester of the academic year 2022/2023, focusing on Class XI Science (Odd Semester).

The population consisted of 64 students from all Class XI Science classes. A purposive sampling technique was used to select participants based on the availability and suitability of the classes for the experimental and control group setup. One class was assigned as the experimental group and the other as the control group. The primary assessment instrument was a multiple-choice test designed to measure critical thinking ability, aligned with established indicators of critical thinking. These indicators included: Drawing conclusions from observations. Identifying assumptions. Employing deductive reasoning. Making logical interpretations. Evaluating arguments. The test initially comprised 25 questions. These questions underwent validation by experts to ensure content relevance and clarity. The instrument was piloted in a trial class to determine its reliability, validity, difficulty level, and discriminatory power. Based on the results of the trial, 17 questions were selected for the final test.

Data were collected using the critical thinking skills test administered to both the experimental and control groups before and after the intervention. The experimental group was taught using the Android-assisted virtual physics learning media developed with Smart Application Creator, while the control group received traditional instruction. The collected data were analyzed using the T-test, performed with SPSS 25.00 for Windows, to determine the significance of differences in critical thinking skills between the experimental and control groups. Descriptive Statistics, Calculating mean, standard deviation, and N-Gain scores for both groups to measure the improvement in critical thinking skills. T-Test Analysis: Conducting an independent samples T-test to evaluate the significance of the intervention at a confidence level of α = 0.05. Effectiveness Analysis: Examining the improvement in critical thinking skills based on N-Gain scores and analyzing performance across the five critical thinking indicators.

Test of Normality

The normality test aimed to ascertain whether the sample being examined exhibited a normal distribution. The Kolmogorov-Smirnov test was utilized for this purpose, with a significance level set at 5%. The hypotheses tested were as follows: H0: The data follows a normal distribution. H1: The data deviates from a normal distribution.

Table 1. The conditions of the Kolmogorov-Smirnov test were established

Probability	Description	Meaning
Sig > 0,05	H0 accepted	The data are normally distributed
Sig < 0,05	H0 rejected	The data is not normally distributed

Scoring of pretest and posttest outcomes

Before data analysis, responses from both the pretest and posttest were evaluated, and students were assigned scores. A correct answer received a score of one, while incorrect answers or unanswered questions were assigned a score of zero. The scoring process followed the formula outlined by Arikunto (2009).

$S = \sum R$ ………………………(1)

Information:

S = Score achieved by students

R = The response of the student is accurate

Test of Homogeneity

The homogeneity test is conducted to examine the equality of variances between two groups (experimental and control classes) to determine whether their data variants are similar or not. In this study, the homogeneity of variances test was employed with a significance level set at 5%. The hypotheses for the homogeneity test are as follows: H0: There is no

Table 2. Conditions for the Homogeneity of Variances Test

Probability	Description	Meaning
Sig > 0,05	H0 accepted	There is no variation between the variance values of the two classes.
Sig < 0,05	H0 rejected	There are disparities in the variance values of the two classes.

Testing of Hypotheses

The hypothesis testing procedure is adjusted based on the results of the normality and homogeneity tests. If the data satisfies the assumptions of normality and homogeneity, parametric statistical tests are employed for hypothesis testing. In this study, the parametric t-test, facilitated by IBM SPSS 25 software, is utilized.

Statistical Hypothesis:

H0: There is no significant difference in the average critical thinking skills between students in the experimental class and those in the control class.

H1: There is a significant difference in the average critical thinking skills between students in the experimental class and those in the control class.

Criteria for Accepting/Rejecting H0:

If sig < α (0.05), H0 is rejected, and H1 is accepted.

If sig > α (0.05), H0 is accepted, and H1 is rejected.

The statistical hypothesis aims to determine whether there exists a disparity between the average critical thinking skills of students in the experimental class, who learn using virtual media based on local wisdom, and those in the control class, who do not utilize such virtual media.

H0: $\mu 1 = \mu 2$

H1: $\mu 1 \neq \mu 2$

N-gain Test: The N-gain, which represents the difference between pre-test and post-test scores, is employed to assess the improvement in scores between the experimental and control classes. The N-gain formula is derived from the equation proposed by Hake (1999): N-gain = (posttest score - pretest score) / (max score - pretest score)

Table 3. Interpretation of N-gain

Score (N-gain)	Criteria
(<g>) >0,70	Outstanding
0,70 >(<g>) >0,30	Moderate
(<g>) <0,30	Substandard

Teaching Material Assessment Questionnaire

The method employed for assessing validity involves the utilization of a questionnaire evaluating teaching materials. This questionnaire collects data on the evaluation of learning tools related to optical materials, utilizing virtual media rooted in local wisdom. The total average score for each aspect is computed using the formula: X = (Number of activities conducted) / (Total number of activities)

Table 4. Teaching Material Assessment Questionnaire Criteria

Score	Criteria
$4 \leq X \leq 5$	Outstanding
$3 \leq X \leq 4$	Moderate
$2 \leq X \leq 3$	Substandard
$1 \leq X \leq 2$	Outstanding

RESULTS AND DISCUSSION

The data from both the control and experimental classes' daily test scores underwent a normality test using the Kolmogorov-Smirnov test with the assistance of IBM SPSS Statistics 25 software. The outcomes of the normality test conducted in this research are presented in Table 5.

Table 5. The Preliminary Assessment of Normality was conducted on the scores from the control and experimental classes. This examination utilized the Kolmogorov-Smirnov test and the results are outlined below.

	Class	Kolmogorov-Smirnova		
		Statistic	Df	Sig.
Test Score	XI-MIPA-2	0.148	30	0.090
	XI-MIPA-1	0.134	34	0.126

The decision regarding the normality test is made according to the significance level (sig.). If sig. ≥ 0.05, H0 is accepted, indicating normal distribution of the data. As shown in Table 18, the sig. values for both classes are ≥ 0.05. Specifically, the sig. value for class XI-MIPA 2 is 0.090, and for XI-MIPA 1, it is 0.126. Therefore, it can be inferred that the data in both classes exhibit a normal distribution.

The homogeneity test was conducted on the daily test score data from both the control and experimental classes. It utilized the Levene Statistical test within the IBM SPSS Statistics 25 software. The outcomes of the homogeneity test are presented in Table 6.

Table 6. Presents The Initial Outcomes of the Homogeneity Test Conducted In Both the Control And Experimental Classes.

Levene Statistic	df1	df2	Sig.
0.658	1	62	0.420
Decisions	Homogeneous Data		

The decision regarding the homogeneity test is made based on the significance level, where if sig. ≥ 0.05, $H0$ is accepted, indicating that the data exhibits homogeneous variance. As depicted in Table 32, the sig. value is ≥ 0.05, specifically 0.420 for the daily test scores in both classes. Therefore, it can be concluded that the data in both classes demonstrate the same or homogeneous variance.

Validation Results from Material Experts

The outcomes of the validation conducted by material experts are illustrated in Table 7.

Table 7. summarizes the results of the validation conducted by material experts.

No	Aspect	Indicator	Number of items	Maximum Score	Score
1	Feasibility Content	Conformity of the material with SK and KD	2	8	7
		Material Accuracy	1	4	3
		Encouraging Curiosity	2	8	6
2	Adequacy of Presentation	Presentation Techniques	1	4	4
		Presentation Support	1	4	4
3	Language Feasibility	Compatibility with language rules	1	4	3
4	Contextual assessment	Contextual Nature	1	4	3
Total			9	36	30
Average					3.33

Based on the table presented, the material expert validation yielded an average score of 3.33, meeting the criteria of being very feasible. Consequently, the material is deemed suitable for use in the research.

Results of Media Expert Validation

The validation results from media experts are presented in the following Table 8.

Table 8. Results of Media Expert Validation

No	Aspects	Indicator	Number of Items	Maximum Score	Score
1	Feasibility Aspects	A. Media Size	1	4	3
		B. Media Display Design	2	8	7
		C. Media Content Design	3	12	10
Total			6	24	20
Average Score					3.33

Based on the validation outcomes provided by media experts in the preceding table, an average score of 3.33 is attained, meeting the criteria for high feasibility, thereby confirming the suitability of the media for research purposes.

N-gain Experiment Group and Control Group

Table 9 displays the average N-gain results for both the Control and Experiment Classes. The N-gain value for each group was determined by computing the difference between the posttest and pretest scores and dividing it by the discrepancy between the ideal and pretest scores. Subsequently, the acquired values were analyzed to ascertain the average N-gain value for each group.

Table 9. The average N-gain outcomes for both the Control and Experiment Classes

Class	N-gain	Interpretation
Control	0.53	Fair
Experiment	0.74	Excelent

Table 9 provides an overview of the average N-gain values observed in both the control and experimental classes. The N-gain values indicate that the average score for the control group is 0.53, suggesting a moderate increase in students' critical thinking skills. Conversely, the average N-gain score for the experimental group is 0.74, indicating a high level of improvement. Notably, the average N-gain in the experimental class surpasses that of the control class. This suggests that the enhancement in critical thinking skills, facilitated by the utilization of virtual media rooted in local wisdom with assistance from smart application developers, exceeded the progress observed in students who did not utilize such resources.

Results of Enhancement per Aspect of Students' Critical Thinking Skills

The outcomes regarding the enhancement per facet of students' critical thinking abilities in both the control and experimental classes are displayed in Table 10.

Table 10. Presents A Comparison of the Percentage Improvement Per Aspect of Critical Thinking Ability Between the Control Class and the Experimental Class.

Class	Stage	Aspects of Critical Thinking Ability Interesting				
		Conclusions of Observation (%)	Identify Assumptions (%)	Deductive Thinking (%)	Make that logically Interpretation (%)	Argument Evaluate (%)
Control	*Pretest*	17.0	29.0	13.0	20.0	20.0
	Posttest	49.4	53.3	46.0	57.0	53.3
Experiment	*Pretest*	29.0	20.0	29.4	24.0	14.7
	Posttest	84.3	80.4	75.2	65.0	88.2

Based on Table 10, it is evident that the percentage increase per critical thinking skill aspect at the pretest stage, prior to treatment, is uniformly low. The control class exhibits the lowest percentage of pretest results at 13% on the aspect of deductive thinking, while the experimental class shows 20% on the aspect of identifying assumptions. However, at the posttest stage, following treatment, the increase per aspect of critical thinking skills is notably higher in the experimental class compared to the control class. The highest percentage of posttest results in the control class is 53.3% for the aspect of evaluating arguments and identifying assumptions, falling under the moderate criteria. Conversely, in the experimental class, it reaches 88.2% for the aspect of evaluating arguments, categorized as high criteria. The breakdown of critical thinking skills percentages per aspect is depicted in the following Figure 1.

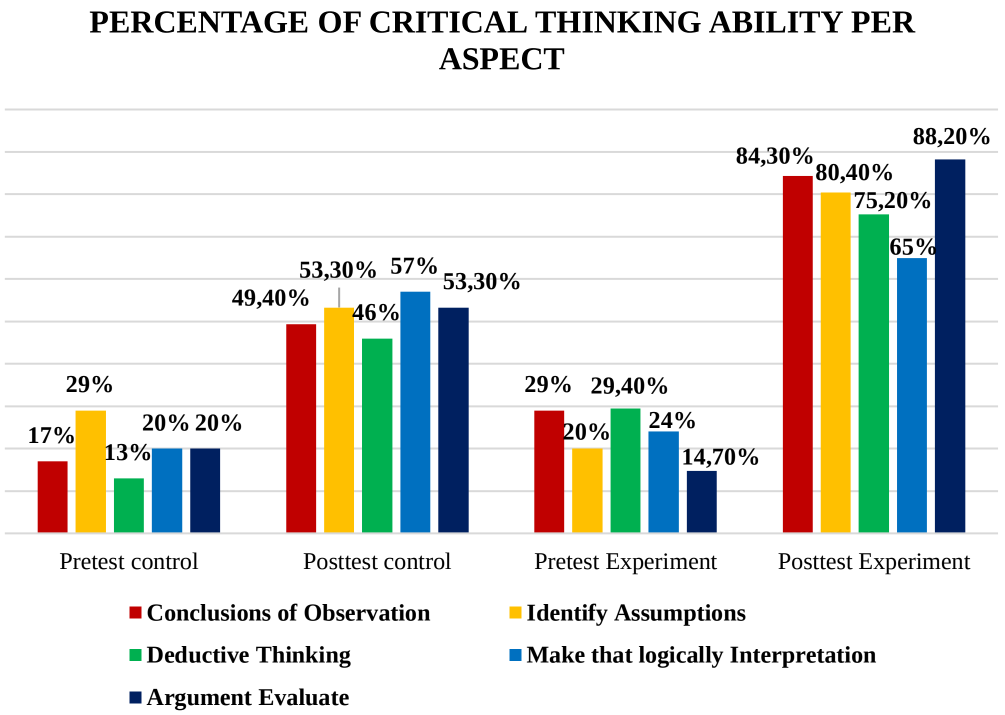

Figure1. Percentage breakdown of critical thinking ability across each aspect.

From the image provided, it's evident that the distribution of critical thinking skills per aspect post-treatment displays varying percentages. In the control class, the highest percentage lies in the aspect of making logical interpretations, totaling 57%. Conversely, in the experimental class, the aspect with the highest percentage is evaluating arguments, standing at 88.20%.

Testing a hypothesis

The results of the statistical prerequisite test indicate that the pretest and posttest data in both classes are normally distributed and homogeneous. Therefore, hypothesis testing in this study was conducted using parametric statistical analysis. The hypothesis was tested with the t-test using the IBM SPSS Statistics 25 software. The results of this hypothesis testing are presented in Table 11.

Table 11. Results of Hypothesis Testing for Students' Critical Thinking Ability

	Class	N	Mean	Std. Deviation	Std. Error Mean	Sig (2-tailed)
Critical Thinking Skills	Control	30	11.08	1.422	0.237	0
	Experiment	34	13.39	1.46	0.243	0

Decisions are made based on the hypothesis testing criteria: if the significance value (2-tailed) is greater than 0.05, H0 is rejected (indicating no difference in the average scores of students in the control and experimental groups). Table 36 shows that the significance value (2-tailed) for the critical thinking ability of the control class is below 0.05, specifically 0.00, and for the experimental class, it is also below 0.05, specifically 0.00. This indicates that H1 is accepted, as the mean score in the experimental class using local wisdom-based virtual media assisted by smart application creators is higher than that of the control class using conventional teaching materials. This demonstrates that the use of local wisdom-based virtual media with the assistance of smart application creators significantly enhances students' critical thinking abilities compared to conventional teaching materials.

Enhancing Critical Thinking Skills Through Local Wisdom-Based Virtual Media via an Android Application.

This study evaluates critical thinking skills using five aspects based on Khusna, A. K. (2018): drawing conclusions from observations, identifying assumptions, thinking deductively, making logical interpretations, and evaluating arguments. Thinking involves internal dialogue, which includes considering, contemplating, analyzing, proving, providing reasons, drawing conclusions, examining thought processes, and understanding how various things are interconnected (Mukhayat, 2004). Critical thinking skills are considered higher-order thinking skills.

Ethnoscience in local wisdom embodies a philosophy and lifestyle reflected in various life aspects, such as social and economic values, architecture, health, and environmental management (Romadi and Kurniawan, 2017). Local wisdom-based virtual media serves as a tool in the learning process, enhancing the experience by creating a more enjoyable and engaging atmosphere. Presented as an Android application, it incorporates elements of local wisdom, such as the torch parade, the sundial at the Grand Mosque of Surakarta, and the Malay Deli traditional house.

The torch parade is a tradition by Muslim communities on the night before Eid al-Fitr. The sundial at the Grand Mosque of Surakarta is used to determine prayer times by using the shadow of a needle above a basin to indicate numbers on the basin's surface. The Malay Deli traditional house, a unique architectural feature in Medan, boasts windows with thick layers of glass.

Studies have shown that mobile-assisted learning significantly enhances students' critical thinking abilities by providing interactive and engaging experiences. For instance, research by Hingkua, P. F., Wirjawan, J. V. D., and Arcana, I. N. (2014) indicated that mobile learning tools in high school physics education improve cognitive skills and student engagement. Similarly, Fauyan, M. (2019) found that Android-based mobile learning boosts critical thinking and motivation in physics, while Herliandry, L. D., Nurhasanah, Suban, M. E., and Kuswanto, H. (2020) demonstrated the effectiveness of digital physics learning applications in engaging students and enhancing cognitive skills.

Overall, the experimental class showed a more significant improvement in critical thinking skills compared to the control class, attributed to the use of local wisdom-based virtual media. The average N-gain of the experimental class was higher than that of the control class by 0.21, supporting the hypothesis that local wisdom-based virtual media positively impacts students' critical thinking abilities. This is evidenced by the higher average scores of the experimental class students, who received virtual media treatment, compared to the control class students, who received conventional treatment.

Pros and Cons of Using Local Wisdom-Based Virtual Media as an Android Application

Over time, the learning process in education demands innovation and creativity due to the evolving nature of physics and the expanding material students need to study. One solution is the use of learning media, such as Android-based or mobile-assisted learning devices (Mardiana, N. 2017; Khoiruddin et al., 2023; Hanoum et al., 2024). Research indicates that mobile learning significantly enhances high school students' cognitive abilities and engagement in physics (Hingkua, P. F., Wirjawan, J. V. D., & Arcana, I. N. 2014). Studies by Fauyan, M. (2019) and Herliandry, L. D., Nurhasanah, Suban, M. E., & Kuswanto, H. (2020) further suggest that mobile-assisted learning tools can effectively improve critical thinking skills and increase overall student engagement.

Using local wisdom-based virtual media for optical material in the form of applications has several advantages and limitations. The advantages include:

1. Enabling students to visually observe videos and images related to optical material based on local wisdom.
2. Providing easy access via Android, allowing students to study independently.

The limitations are:

1. The study focused only on optical material, so the findings cannot be generalized to other subjects.
2. The research controlled only for the use of virtual media based on local wisdom on students' critical thinking skills, without considering other variables like spirituality and attitudes during the learning process.

Student Motivation and Response to Using Local Wisdom-Based Virtual Media Supported by Smart Application Creator for Optical Material

The analysis of the student motivation questionnaire reveals very high levels of motivation across all indicators. Specifically, the desire and interest in learning scored 89%, the encouragement and need to learn also scored 89%, a conducive learning environment scored 86%, and attitudes, expectations, and ideals scored 87%.

Student responses play a critical role in evaluating the effectiveness and engagement of instructional media. In this study, the high positive response rates 92% for language feasibility, 94% for graphic feasibility, and 91% for content feasibility indicate that students found the local wisdom-based virtual media for optical material highly acceptable and effective. The data suggest that the design and integration of local cultural elements into the virtual learning media resonate well with students, fostering engagement and relevance.

These findings align with previous research that emphasizes the importance of culturally contextualized learning materials in improving student engagement and comprehension. Studies have shown that integrating local wisdom into educational media enhances relatability, thereby supporting higher-order cognitive processes such as critical thinking and problem-solving. For instance, reported similar positive outcomes when local cultural elements were included in teaching materials for other subjects. However, the current study contributes to the body of literature by specifically demonstrating these effects within the context of physics education.

The positive reception of local wisdom-based virtual media highlights its potential as a scalable instructional approach. The findings suggest that incorporating cultural relevance into digital learning tools can effectively engage students and enhance their learning experience. This approach not only supports the development of critical thinking skills but also fosters an appreciation of local cultural heritage, contributing to a holistic educational experience.

The novelty of this study lies in its integration of local wisdom with Android-assisted virtual learning media for teaching physics, a subject often perceived as abstract and challenging. Unlike traditional methods, this approach bridges cultural familiarity and technological innovation, making the learning process more accessible and meaningful for students. While the results are promising, there are several limitations to consider. The study was conducted in a specific region with unique cultural characteristics, limiting the generalizability of the findings to other contexts. The sample size was relatively small, potentially affecting the robustness of the conclusions. The study focused on students' responses and critical thinking skills but did not assess long-term retention or transfer of knowledge.

Future Research: Extend the study to different regions and cultural contexts to validate the effectiveness of local wisdom-based media across diverse student populations. Long-Term Studies: Conduct longitudinal studies to examine the impact of such media on students' retention and application of knowledge. Broader Integration: Develop and evaluate similar media for other challenging subjects, such as mathematics and chemistry, to explore the broader applicability of this approach. Teacher Training: Provide professional development opportunities for educators to effectively integrate local wisdom and digital tools into their teaching practices.

CONCLUSION

The utilization of local wisdom-based virtual media, supported by smart application creators, significantly enhances students' critical thinking skills in learning optical material. The hypothesis test results indicate a p-value of 0.00, confirming a highly significant effect. The calculated effect size (0.74) falls within the high category, demonstrating the substantial impact of this innovative approach on students' cognitive development. This study underscores that integrating culturally relevant content into technologically advanced media creates a stimulating learning environment. This approach not only promotes deeper understanding and critical analysis but also bridges cultural familiarity with modern pedagogical practices. Students in the experimental class exhibited notably higher critical thinking skills compared to their counterparts in the control group, validating the effectiveness of local wisdom-based virtual media in fostering higher-order cognitive skills.

The findings suggest that incorporating local cultural elements into virtual learning tools can be a powerful strategy to engage students, particularly in abstract subjects like physics. Educators and curriculum developers should consider adopting culturally contextualized teaching materials to enhance relevance and relatability. Education policymakers can leverage these results to promote the development and dissemination of culturally enriched digital learning resources. Supporting such initiatives could improve educational outcomes at a broader scale. This research contributes to educational theory by proposing a model for integrating local wisdom with digital media to enhance critical thinking skills. The findings suggest that the alignment of culturally familiar content with interactive technology not only aids in knowledge acquisition but also fosters critical cognitive processes, offering a new perspective on effective educational interventions. This study provides a foundation for further exploration into the broader applicability of local wisdom-based virtual media across different subjects, age groups, and cultural contexts. Additionally, longitudinal studies could assess the long-term impact of this approach on knowledge retention and application.

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AUTHOR CONTRIBUTIONS

All authors have contributed significantly to the development and completion of this study. Nana Mardiana designed the research, developed the local wisdom-based virtual media, and conducted the data collection, Nani Mardiani performed the statistical analysis and interpreted the results. Bania Maulina contributed to the literature review, manuscript writing, and final revisions. All authors reviewed and approved the final manuscript.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

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