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Improving Critical Thinking Skills of High School Students in Physics Learning with Smartphone-Simulation Assisted Inquiry Model

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ABSTRACT

Objective: *Research to describe the improvement of students' critical thinking skills with the Smartphone-Simulation assisted inquiry learning model.* ***Method:*** *This research employed a quantitative descriptive approach, utilizing the data collected. Primary data were obtained from the results of skills tests, observations of learning implementation, and student responses. Furthermore, secondary data was obtained from a literature review to support the primary data.* ***Results:*** *The smartphone simulation media-assisted inquiry model has a positive effect on improving students' critical thinking skills, with an N-Gain score of 0.675. The inquiry learning model, combined with critical thinking, is closely related, focusing on high-level thinking processes that are systematic, reflective, and experience-based.* ***Novelty:*** *Dynamic visualization through the use of smartphone simulations greatly helps improve students' critical thinking skills, accelerating and strengthening the development of their critical thinking in real terms. This is achieved through information transfer and the construction of understanding through active and reflective thinking processes. It is hoped that this research can be one of the implementations of innovative learning planning assisted by digital media.*

INTRODUCTION

21st-century skills are currently necessary to enhance a person's ability to coexist with the technological revolution (Jayadi et al., 2020). 21st-century learning skills encompass critical thinking, innovation, creativity, and scientific knowledge, as well as communication and collaboration skills (M. Astuti et al., 2024; Kennedy & Sundberg, 2020). One of these skills is critical thinking, which is the process of thinking actively and rationally with full awareness by considering the results of information (Blair et al., 2021; Facione, 2015). In addition, by thinking critically, a person can reflect on their thoughts rationally, based on reasoning, to determine the central ideas or concepts necessary to solve a problem (Lintangesukmanjaya, Prahani, et al., 2024). Critical thinking itself is a problem-solving skill that involves logical analysis and considering facts and arguments in a reflective manner (Neswary & Prahanı, 2022). A person can solve problems, simple or complex, by thinking critically. Thus, this skill is essential for improving the development of education today (Ramona et al., 2023).

Education problems in Indonesia arise due to the lack of educational equality that has been ongoing. The results of the PISA study found that Indonesia ranked 68th out of 72 OECD countries, with a decrease in literacy and numeracy skills in 2022 (Ismawati et al., 2023; Moh Slamet Sutrimo et al., 2024). In general, according to educational statistics, only 60% of schools provide educational services that align with maximum educational achievements. This is constrained by media, facilities, and human resources that are less competent in creating quality education (Astuti et al., 2021). Based on data from several previous studies, the level of critical thinking among high school students in physics and science learning experiences is problematic despite the importance of these skills (Lintangesukmanjaya et al., 2024; Saphira & Prahani, 2022). Other facts are supported by statistical data that the relatively low cognitive ability scores in education are C4-C5 (Yusuf et al., 2022). This supports that the low level of critical thinking skills of students is also a problem.

The results of identifying the problem of declining students' critical thinking skills are the use of learning models that have not yet optimally improved students' skills. To date, conventional learning models commonly used have not been effective in improving students' critical thinking skills (Yulianti et al., 2021). So, it is necessary to implement an experience-based learning model such as the inquiry model (Susilawati et al., 2021; Yulianti et al., 2021). With inquiry learning, students can actively analyze, evaluate, and reflect on the findings they find independently (Solikah & Novita, 2022). This is the reason that inquiry supports improving students' critical thinking.

However, in science learning, such as physics, abstract material is one of the weaknesses of inquiry where there are limitations in learning that require optimal media to improve student understanding. Therefore, as an effort to implement digital-based learning in this era of technology adoption, one of the integrated digital visualization media used is virtual simulation (Verawati et al., 2022). Virtual simulation provides an interactive experience and features attractive visualizations, making it suitable for physics learning that requires visual support for abstract concepts (Muflikhun & Setyarsih, 2022). Virtual simulation can now also be used on lighter and more flexible platforms such as smartphones, tablets, or laptops. This makes it easier for students to access learning through virtual simulations.

Based on the description above, the purpose of this study is to describe the improvement in students' critical thinking skills using the inquiry learning model assisted by Smartphone Simulation. The analysis was conducted to describe the effectiveness and responses of students in learning physics with the inquiry learning model assisted by virtual simulation. It is hoped that this study can be one of the implementations of innovative learning planning assisted by digital media.

RESEARCH METHOD

General Background

This study employed a quantitative descriptive method, utilizing the data obtained. Quantitative research examines samples by analyzing data statistically using specific numerical methods (Susanto et al., 2020; Usparianti et al., 2023). Primary data were obtained from the results of skill tests, observations of learning implementation, and student responses. Furthermore, secondary data were obtained from a literature review regarding the theoretical basis of the research. The following is a draft of the research design,

Figure 1. Research design

Research Sample

This research was conducted at Ngimbang High School, East Java. The research sample was taken by purposive sampling from the entire population studied. The sample consisted of 62 students. In addition, data collection was also conducted by gathering data from relevant research, and data reduction was performed to strengthen the findings in the field. Based on the results of the data presentation, generalizations can be made to inform and verify new findings (Estinfort et al., 2022). From the results of the data analysis, knowledge was gained about the effect of using digital teaching materials on improving critical thinking in physics learning.

Instrument and Procedures Data Analysis

This research was conducted using instruments that included critical thinking skills tests, observation sheets for the implementation of inquiry-based learning, and student response questionnaires. The virtual simulation media used was the PhET simulation that had been integrated into students' smartphones. The following is a list of research instruments.

Table 1. Research instrument

Research Instrument	Objective	Analysis Indicators
Implementation Observation	Implementation of Inquiry Learning Syntax	Likert Scale (1: Less, 2: Sufficient, 3: Good, 4: Very Good)
Critical Thinking Skills Test Sheet	Analysis of Students' Critical Thinking Profiles	Quantitative Descriptive Analysis and Non-Parametric Tests
Response Questionnaire	Practicality Response to Implement Inquiry and Smartphone Simulation	Likert Scale (1: Disagree, 2: Less Agree, 3: Agree, 4: Strongly Agree)

The analysis was conducted to describe the improvement of students' critical thinking skills. The difference test used was the t-test for parametric tests and the Wilcoxon test for non-parametric tests (Hidayat & Aripin, 2023). Indicators from the analysis of each instrument are presented in Table 1, where each instrument has its indicators to determine the achievement of the data obtained.

RESULTS AND DISCUSSION

Results

Based on the results of a study conducted with 62 students using the inquiry learning model, the implementation of learning, analysis of the increase in critical thinking skills, and student responses were obtained. The results of the implementation of inquiry learning ran smoothly and by the syntax used as follows,

Table 2. Results of inquiry learning implementation

No	Assessment Aspects	Average	Persentase (%)	Category
Opening				
1	The teacher opens the lesson with greetings, prayers, checking attendance, providing apperception, motivation and conveying the learning that will be carried out.	3.70	92.50	Very good
Phase 1: Identification of Phenomena and Symptoms				
2	The teacher gives stimulus questions related to the learning material.	3.80	95.00	Very good
3	The teacher encourages students to see the phenomena of mechanical waves and electromagnetic waves in everyday life.	3.75	93.70	Very good
4	The teacher asks several students to explain the meaning of waves and their characteristics.	3.70	92.50	Very good
Phase 2: Formulating Problems and Hypotheses				
5	The teacher asks students to find ideas from the problem formulation with the teacher's guidance (clarification).	3.65	91.25	Very good
6	The teacher asks students to make hypotheses based on the problems they find.	3.70	92.50	Very good
7	The teacher guides students to find facts based on hypotheses that are in accordance with the problem formulation.	3.90	97.50	Very good
Phase 3: Designing the Experiment				
8	The teacher divides students into groups of 5-6 students.	3.75	93.75	Very good
9	The teacher gives instructions to students to carry out practical activities.	3.45	86.25	Very good
Phase 4: Conducting the Experiment				
10	The teacher asks students to do practical work assisted by smartphone simulations.	3.80	95.00	Very good
Phase 5: Data Analysis				
11	The teacher asks students to compare the hypothesis with the results of the practicum.	3.85	96.25	Very good
12	The teacher selects a group to present the results of their group's discussion based on the data found.	3.70	92.50	Very good
Phase 6: Conclusion and Evaluation				
13	The teacher asks students to conclude the results of the activities that have been carried out.	3.80	95.00	Very good

No	Assessment Aspects	Average	Persentase (%)	Category
14	The teacher emphasizes the concepts that students have discovered about the characteristics of waves.	3.45	86.25	Very good
Closing				
15	The teacher ends the lesson by praying and giving greetings and saying thank you.	3.80	95.00	Very good
	Average	3.72	93.00	Very good

Three physics teachers collected the results of the observation. The learning activities employed an inquiry-based learning approach, which requires students to gain knowledge through their efforts (Conradty & Bogner, 2020; Neuhaus, 2020). Based on the six inquiry learning syntaxes carried out in one meeting, the following comparison of results was obtained,

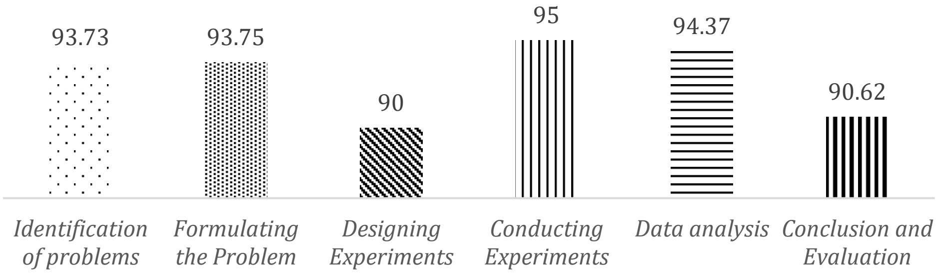

Figure 2. Comparison of inquiry syntax implementation results

Based on Figure 2, the implementation of inquiry learning activities yields the highest results in experimental activities, where students are highly enthusiastic about experimenting with smartphone simulations due to their visual and interactive nature (Verawati et al., 2022). Furthermore, to measure critical thinking skills, the results of the pre-test and post-test analysis were carried out using critical thinking test instruments given to students. The following are the results of the normality and homogeneity tests of students' critical thinking skills tests.

Table 3. Results of normality and homogeneity tests

	Kolmogorov-Smirnov[a]			Shapiro-Wilk			Homogeneity of Variance
Class	Statistic	df	Sig.	Statistic	df	Sig.	
Pre-test A1	.265	30	.000	.820	30	.000	.000
Post-test A1	.348	30	.000	.763	30	.000	
Pre-test A2	.318	32	.000	.821	32	.000	
Post-test A2	.238	32	.000	.888	32	.003	

The results in Table 3 indicate that the significance is obtained. A Value of $p < 0.05$ indicates that the data is not normally distributed (Adhelacahya et al., 2023; Risnita & Bashori, 2020). The following analysis employed non-parametric methods to assess the results of the difference test on the effect of learning implementation on critical thinking skills. The following are the results of the Wilcoxon test obtained,

Table 3. Different test results

		N	Mean Rank	Sum of Ranks
Post test A1 - Pre test A1	Negative Ranks	0[a]	.00	.00
	Positive Ranks	30[b]	15.50	465.00
	Ties	0[c]		
	Total	30		
Post test A2 - Pre test A2	Negative Ranks	0[d]	.00	.00
	Positive Ranks	32[e]	16.50	528.00
	Ties	0[f]		
	Total	32		

Test Statistics[a]		
	Post test A - Pre test A	Post test B - Pre test B
Z	-4.862[b]	-4.969[b]
Asymp. Sig. (2-tailed)	.000	.000

Based on the results of Asymp. Sig. (2-tailed) At $p < 0.05$, it was found that the learning process provided influenced or differed in the results of critical thinking skills (Ogegbo & Ramnarain, 2022). Inquiry learning assisted by smartphone simulation enhances the development of critical thinking skills. This is evident from the results of negative ranks and positive ranks in each class. For more details, refer to Table 4, specifically the N-Gain results for 62 students.

Table 4. N-Gain pre-test and post-test results

Class	Score	Indicator
A1	0.68	medium
A2	0.67	
Average	0.675	

The increase was obtained by comparing the pre-test and post-test results, which showed that students' critical thinking skills improved by 0.675, categorized as moderate. The following is a comparison of the scores of students' critical thinking indicators,

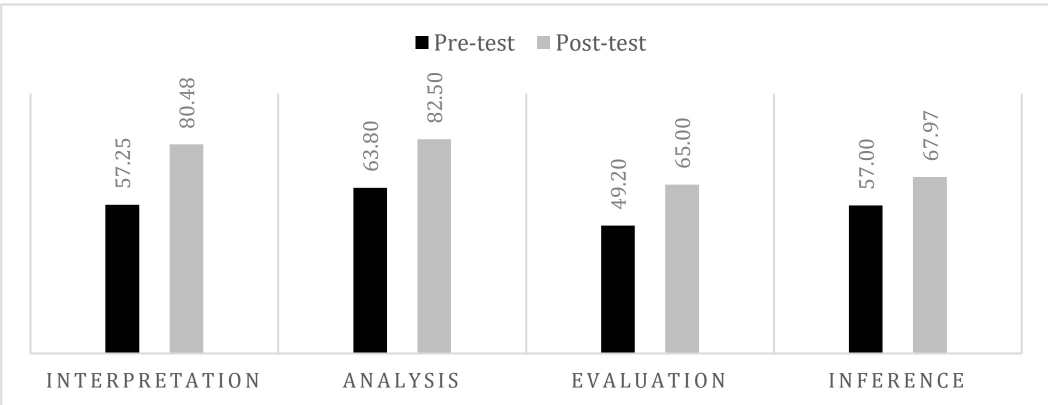

Figure 3. Critical thinking indicator score comparison results

Overall, the value of low critical thinking skills has increased in each of the critical thinking indicators. Of the four critical thinking indicators (interpretation, analysis, evaluation, and inference) according to Facione (Bhakti et al., 2023; Facione, 2015), the indicator that experienced the highest increase was interpretation, and the lowest increase was in inference.

Finally, to determine how students respond to learning related to the implementation of smartphone simulation-assisted inquiry, the following are the results of student responses.

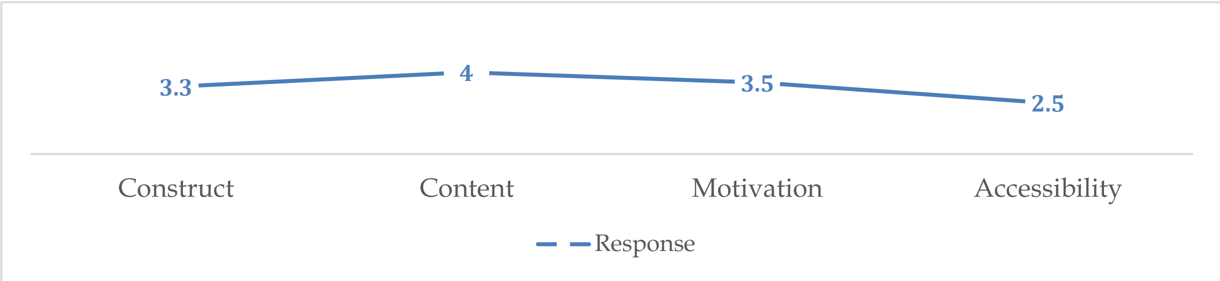

Figure 4. Student response results

On a scale of 1-4, there is no average response result showing a value below 2, indicating that the student's response related to the learning carried out is excellent. It can be seen from Figure 4 that the highest response is in the content aspect, which shows that the use of smartphone simulation-assisted inquiry is interesting in terms of visuals and animation (Meng et al., 2022). While the lowest value is in the accessibility aspect, this is influenced by the use of simulations that are limited to only one material or exploration activities are limited by the scope of the virtual simulation used by students.

Discussion

The implementation of inquiry learning assisted by smartphone simulation went well, as shown in Table 2, and through the syntax of inquiry learning consisting of identifying phenomena and symptoms, formulating problems, designing experiments, conducting experiments, analyzing data and conclusions, and evaluating (Conradty & Bogner, 2020; Solikah & Novita, 2022) obtained satisfactory results. The learning activities were carried out smoothly, especially during the experiment's implementation.

Figure 5. Implementation of learning activities

In the experimental activities, students' enthusiasm increased, which was attributed to the use of engaging smartphone simulations (Doyan et al., 2021; Meng et al., 2022). The use of smartphone simulations in learning has a close relationship with the inquiry learning model, especially in the context of digital-based learning (Yulianti et al., 2021). This is because the inquiry learning model emphasizes the process of students discovering knowledge through observation, experimentation, and problem-solving. Meanwhile, students can experiment with various variables in smartphone simulations to identify patterns or find answers to their questions. The emergence of this feedback can increase students' enthusiasm, enabling them to develop their high-level thinking skills, including critical thinking skills (Anggraeni et al., 2024).

Furthermore, based on the analysis of the increase in critical thinking obtained from the non-parametric test results, as shown in Table 3, the inquiry model assisted by smartphone simulation media has a positive effect on improving students' critical thinking skills. Although the N-Gain score result is 0.675, indicating a moderate category, overall, students' critical thinking skills have increased significantly. The inquiry learning model, which incorporates critical thinking, is closely related because both focus on systematic, reflective, and experience-based high-level thinking processes (O'Flaherty et al., 2024). Coupled with dynamic visualization through the use of smartphone simulation, which is very helpful in improving students' critical thinking skills (Yulianti et al., 2021). Thus, the use of smartphone simulation in inquiry learning accelerates and strengthens the development of student's critical thinking in real terms through the transfer of information by constructing understanding through active and reflective thinking processes.

However, although the overall critical thinking indicators have increased, there are differences in the number of improvement scores for each indicator. The indicator with the highest increase is interpretation. This is related to inquiry learning, which provides students with access to learn to formulate problems and collect data that enables students to understand and explain the meaning of information (Neuhaus, 2020; Ubaidillah et al., 2023). Then, the indicator with the lowest increase is the inference indicator, which means drawing a conclusion. Students' difficulties in inference stem from the challenge of interpreting answers they already know (As-Syauqi et al., 2024). Another difficulty is generalization, which must consider facts and data from experiments that have previously yielded results. Although inference is at its lowest increase, the evaluation indicator is also an important one that should not be underestimated, as it is the lowest indicator during the initial skills test. This means that students also struggle to evaluate, specifically assessing the credibility of sources (good or bad) based on the strength of their arguments (Lintangesukmanjaya et al., 2024).

Based on all of this, it is necessary to correlate the experimental findings with the students' responses to obtain evaluations and recommendations for further research (Maharani & Prahani, 2024). Overall, the response results stated that the smartphone simulation-assisted inquiry learning activities received a good response from students. However, an evaluation is needed due to the limited accessibility, where the use of simulations on smartphones is currently restricted to a single type of physics material, as well as the limited amount of data that can be utilized. So far, the integration of research simulations has been used with virtual lab pages that have been developed for free on the global web. Further research recommendations can be developed into virtual simulations that can be fully integrated with critical thinking skills and inquiry-based learning to maximize student skills.

CONCLUSION

Fundamental Finding: The inquiry model, assisted by smartphone simulation media, has an effect on improving students' critical thinking skills, with an N-Gain score of 0.675. **Implication:** The inquiry learning model, combined with critical thinking, is closely related, focusing on high-level thinking processes that are systematic, reflective, and experience-based. Dynamic visualization through the use of smartphone simulations significantly enhances students' critical thinking skills, accelerating and strengthening their critical thinking development in real-world contexts. This is achieved through information transfer and the construction of understanding through active and reflective thinking processes. **Limitation:** Limited accessibility is a concern, as the use of simulations on smartphones is currently restricted to a single type of physics material, and the available data is limited. So far, the integration of research simulations has been used with virtual lab pages that have been developed for free on the global web. **Future Research:** Further research recommendations can be developed into virtual simulations that can be fully integrated with critical thinking skills and inquiry-based learning to maximize students' skills.

AUTHOR CONTRIBUTIONS

Rahmatta Thoriq Lintangesukmanjaya: Conceptualization, Methodology, and Validation; **Akhmad Iswardani**: Methodology and Writing - Original Draft; **Budi Jatmiko**: Formal Analysis, Resources. **Zainul Arifin Imam Supradi**: Data Curation, Project Administration, and Writing - Original Draft. All authors have read and approved the final version of this manuscript.

DECLARATION OF COMPETING INTEREST

The authors declare no known financial conflicts of interest or personal relationships that could have influenced the work reported in this manuscript.

DECLARATION OF ETHICS

The authors declare that the research and writing of this manuscript adhere to ethical standards of research and publication, in accordance with scientific principles, and are free from plagiarism.

DECLARATION OF ASSISTIVE TECHNOLOGIES IN THE WRITING PROCESS

The authors declare that generative artificial intelligence (Gen AI) and other AI-assisted tools were used judiciously, not excessively, during the research and preparation of this manuscript. Specifically, ChatGPT was used for brainstorming; Grammarly for grammar and style correction. All AI-generated materials have been reviewed to strengthen data accuracy, completeness, and compliance with ethical and scientific standards. The authors are fully responsible for the final content of the manuscript.

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