Blended Learning Integration in Physics: Advancing Critical Thinking Skills on Optical Instrument Concepts

Yesma Aini[1], Wafiqoh Zakiah[3]
[1]Muhammadiyah 8 Senior High School Ciputat, Banten, Indonesia
[2] Physics Education Department, Universitas Islam Negeri Syarif Hidayatullah Jakarta, Jakarta, Indonesia

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ABSTRACT

Purpose of the study: This study aims to determine the effect of the blended learning model on students' critical thinking skills on the concept of optical instruments.

Methodology: The research sample was obtained through purposive sampling, consisting of class XI IPA 1 (experimental) and class XI IPA 2 (control), with 29 students in each class, for a total of 58 students. This study employed a quasi-experimental method with a nonequivalent control group design. The instrument was an essay test consisting of 10 items based on Robert H. Ennis's critical thinking indicators. Data were analyzed using parametric tests (*t-test*) with the assistance of the SPSS program.

Main Findings: The paired samples *t*-test at $\alpha = 0.05$ yielded a Sig. (2-tailed) value of 0.001, indicating that H_0 was rejected and H_1 accepted. This confirms a significant difference in students' critical thinking skills between the experimental and control classes. The blended learning model enhanced students' performance, with the experimental class achieving a higher N-gain (0.63, medium) than the control class (0.33, medium). Nonetheless, improvement remained modest in the indicator of answering clarification questions (N-gain = 0.43).

Novelty/Originality of this study: This study highlights the originality of integrating a blended learning model supported by Google Classroom to improve students' critical thinking skills in physics, specifically on optical instruments. The novelty lies in combining digital learning platforms with classroom instruction, demonstrating not only improved learning outcomes but also fostering students' independence and active engagement, thus extending existing knowledge in blended physics education.

Corresponding Author:
Yesma Aini,
Muhammadiyah 8 Senior High School Ciputat,
Jl. KH. Dewantara No.23, Cipayung, Ciputat, Tangerang Selatan, Banten 15411, Indonesia
Email: yesmaaini21@gmail.com

1. INTRODUCTION

Educational developments in the 21st century require students to possess higher-order thinking skills, one of which is critical thinking. This skill is crucial for dealing with the complexity of real-life problems, including science learning in schools [1]-[3]. Critical thinking enables students to analyze, evaluate, and solve problems systematically [4], [5]. According to Ennis [6], Critical thinking is a reflective process that focuses on making reasoned decisions about what to believe or do. Therefore, designed learning must be able to foster students' critical thinking skills.

Physics, as a branch of science, requires students not only to master theory but also to be able to apply it to solve everyday problems. One important concept in physics studied in high school is optical instruments, such as microscopes, cameras, and telescopes [7], [8]. The concept of optical instruments emphasizes advanced analytical skills because it relates to the principles of light and its applications in life [9], [10]. However, many students struggle to grasp these concepts due to their abstract nature and the need for visual representation [11], [12]. This highlights the need for innovative learning strategies to help students grasp the concepts while simultaneously developing their critical thinking skills.

The blended learning model is an approach that combines face-to-face and online learning. This model provides students with the flexibility to access learning materials, discuss, and practice independently or collaboratively [13], [14]. Blended learning can create a more meaningful learning experience because it combines direct interaction with the use of technology [15]-[17]. Furthermore, blended learning has been shown to increase student engagement in the learning process [18], [19]. Therefore, blended learning is seen as a potential way to develop students' critical thinking skills in the concept of optical instruments.

Previous research has demonstrated that blended learning is effective in improving students' critical thinking abilities. For example, research by Martiana, Dwiningrum, & Aw [20] showed that blended learning has a positive effect on the development of critical thinking skills at various levels of education. Their meta-analysis confirmed that this model provides a more in-depth learning experience than traditional methods. This finding aligns with research by Sinaga & Simanjuntak [21] which showed a significant increase in physics students' critical thinking skills through blended learning. This demonstrates that blended learning has great potential in the context of science learning.

Although previous research has shown positive results, several other studies have found that blended learning does not always have a significant impact on critical thinking. Widyaningrum et al. [22] For example, it was reported that blended problem-based learning did not significantly impact critical thinking skills in buffer solution chemistry. This indicates that the effectiveness of blended learning is highly dependent on the learning design, material characteristics, and the preparedness of both students and teachers [23], [24]. Therefore, further research on the concept of optical instruments, which has both visual and applicative characteristics, is crucial. This aims to ensure the consistent effectiveness of blended learning in developing critical thinking skills.

Based on this description, research on the effect of blended learning models on students' critical thinking skills in the concept of optical instruments is highly relevant. This research is expected to provide practical contributions for teachers in designing physics lessons that are more effective, adaptive, and appropriate to current needs. Through this research, it is hoped that students will not only understand the concept of optical instruments but also be trained in critical thinking to solve problems scientifically. Therefore, the results of this study will provide both theoretical and practical benefits in the field of science education.

2. RESEARCH METHOD

The research method used was a quasi-experimental method, a method that has a control group, but cannot fully control external variables that influence the experiment [25], [26]. The research design used in this study was a nonequivalent control group design [27], [28]. An overview of the research design for the experimental and control classes can be seen in Table 1 below.

Table 1. Research Design

Group	Pre-test	Treatment	Post test
A	Y1	XA	Y2
B	Y1	XB	Y2

Information:
A= Experimental Class
B= Control class
X_A= Treatment using digital assignments
X_B= Treatment using conventional assignments (print)
Y_1 = Initial test (pretest) before treatment
Y_2 = Final test (posttest) after treatment

The population in this study was all students of Muhammadiyah 8 High School, Ciputat. The sample size was a subset of the population and its characteristics. The sample consisted of eleventh-grade science students. The sample was drawn from a reachable population using purposive sampling, with sampling based on specific considerations. The sample selection included groups with relatively similar ability levels. The sample selection resulted in eleventh-grade science 1 as the experimental class and eleventh-grade science 2 as the control class.

The instruments used in this study were: A critical thinking ability test was a descriptive-type test used for the pretest and posttest. The student response questionnaire consisted of several aspects assessed by students. This questionnaire was used to measure student responses to the blended learning model on the concept of optical instruments. The questionnaire used was a closed-ended questionnaire with alternative answers: strongly agree, agree, disagree, and strongly disagree. The test met the requirements for a good instrument, namely: validity, reliability, discriminatory power, and difficulty level. The grid for the test instrument is in Table 2.

Table 2. Critical Thinking Skills Instrument Grid

No	Critical Thinking Skill	Indicator	Item No.
1	Basic Classification	Focus on a question	1, 2*, 3*
2	Basic for Decision Making	Assessing the credibility of sources	4*, 5, 6*, 7*, 9
3	Inference	Making and determining the result of judgment	8*, 12*
		Making value statements	10
		Giving reasonable assumptions	11
4	Strategies and Tactics	Determining an action	13
		Interacting with others	14*, 15*, 16*

Note: (*) = questions used with a Cronbach alpha value of 0.95

The questionnaire used in this study was the Likert model. The left-hand grid of the questionnaire instrument in this study is shown in Table 3 below.

Table 3. Non-test instrument grid (questionnaire)

No	Type of Learning	Observed Aspect	Question	Nature of Question	Item No.
1	Classroom Learning	Attitude – Students' attitude toward classroom learning	Physics learning facilitated by the teacher in class helps me understand the subject matter easily.	Positive	1
			The general overview explained by the teacher at the beginning of learning helps me understand the outline of the material and learning objectives to be achieved.	Positive	2
			I do not need to answer questions asked by the teacher because it will not affect my knowledge of the material taught.	Negative	3
			During group discussions or presentations, I just need to remain silent and do not need to give any response.	Negative	4
		Interest – Students' interest in classroom learning	By doing presentations in front of the class, I can also practice my speaking skills.	Positive	5
			I should often express my opinions both in discussion and presentation activities.	Positive	6
			I just need to follow the teaching and learning activities in class without caring about the results I should achieve after the lesson.	Negative	7
			Learning in groups only makes me feel uncomfortable.	Negative	8
		Relation between classroom learning and understanding of physics material	After classroom learning, I am more proficient in interpreting physics problems and solving them.	Positive	9
			From the beginning, I already understood the material on optical instruments so I do not need to pay attention to the teacher's explanation.	Negative	10
2	Online Learning (E-	Attitude – Students' attitude toward online	Online learning helps me understand the physics material I study more deeply.	Positive	11

Learning)	learning with Google Classroom	Through online learning I find new knowledge that I have not obtained from classroom learning.	Positive	12
		Through online learning, I get the opportunity to study physics anywhere and anytime without being limited by time.	Positive	13
		If I have difficulties, I just need to wait for the teacher's explanation of the answers instead of finding solutions from online sources.	Negative	14
		I do not need to routinely visit the learning website or engage in online learning.	Negative	15
		Online learning is held only to obtain extra credit from the teacher.	Negative	16
	Interest – Students' interest in online learning	Because I can interact well with peers and teachers without hesitation, I feel enthusiastic in participating in online learning.	Positive	17
		I think my teacher will not mind if I do not attend the online physics learning sessions.	Negative	18
	Relation between e-learning and understanding of physics material	The teaching materials presented via Google Classroom help me better understand the material studied.	Positive	19
		Doing practice problems online only wastes my time.	Negative	20

The research procedure can be seen in Figure 1 below.

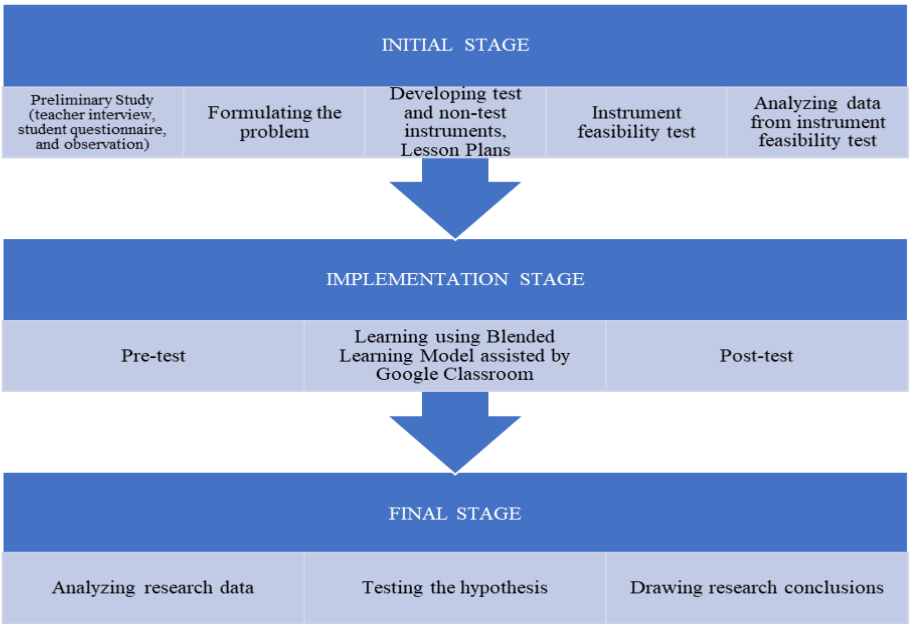

Figure 1. Research Procedure

Data analysis in this study used SPSS software to test normality, homogeneity, and hypothesis. Hypothesis testing used parametric statistical analysis in the form of a T-test using SPSS software. The N-gain test was used to determine the "judgment value" of the results of the improvement that occurred (high/medium/low). N-Gain (Normalized Gain) was used to determine the improvement in students' critical thinking skills. The N-Gain results can be obtained using the following equation.

$$N - Gain = \frac{\text{Posttest score} - \text{pretest score}}{\text{maximum score} - \text{pretest score}}$$

The N-Gain testing criteria according to Hake can be seen in table 4.

Table 4. N-Gain Testing Criteria

N-Gain Value (g)	Criteria
N-gain < 0,3	Low
N-gain 0,3 – 0,7	Medium
N-gain > 0,7	High

3. RESULTS AND DISCUSSION

The data described are the pretest and posttest results for the experimental and control classes. The pretest data were obtained before the two classes were given different learning methods to ensure the initial abilities of both research classes were equal. Meanwhile, the posttest data were obtained after both classes had implemented learning using different learning models. The researchers used the same posttest questions as the pretest questions. The pretest and posttest data obtained from the experimental and control classes are as follows:

3.1. Pretest Result Data

Students' initial critical thinking skills before receiving treatment can be seen from the pretest results. The pretest results for the experimental and control classes can be seen in Figure 2.

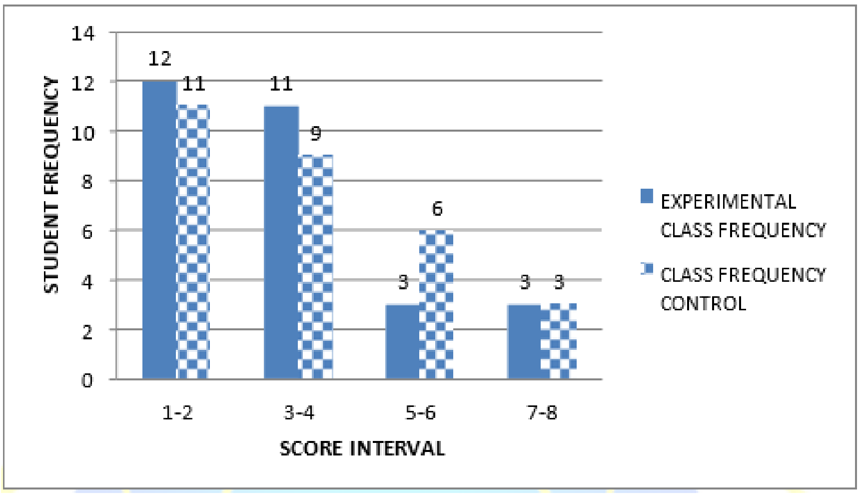

Figure 2. Bar Chart of Distribution of Pretest Scores for Critical Thinking Skills

Figure 2 shows the distribution of student pretest scores at each interval in the control and experimental classes, with a maximum score of 40 (a total of 10 items). Twelve students in the experimental class and 11 in the control class achieved a score of 1-2. Eleven students in the experimental class and nine in the control class achieved a score of 3-4. Three students in the experimental class and six in the control class achieved a score of 5-6. Three students in the experimental class and six in the control class achieved a score of 7-8.

The highest pretest scores in both the control and experimental classes were in the 7-8 interval, with 3 students in the experimental class and 3 in the control class. The lowest pretest scores in both classes were in the 1-2 interval, with 23 students: 12 students in the experimental class and 11 students in the control class.

Based on statistical calculations, several values of the central tendency and dispersion of the data were obtained from the pretest scores, as shown in Table 5.

Table 5. Measures of Centralization and Distribution of Pretest Data Results

Data Centering and Distribution	Experimental Group	Control Group
Lowest Score	1	1
Highest Score	8	8
Mean	3.379	3.586
Median	3	4
Mode	2	2
Standard Deviation	1.860	1.937

. Table 5 shows that the lowest score obtained by the experimental class and the control class is the same, namely 1. While the highest score in the experimental class and the control class is the same, namely 8. The average score obtained by the experimental class is 3.379 and the control class is 3.586. The median obtained by the experimental class is 3 and the control class is 4. The mode obtained by the experimental class and the control class is both 2. The standard deviation in the experimental class is 1.860 and in the control class is 1.937.

3.2. Posttest Result Data

Students' final critical thinking skills after completing the learning process can be seen from the posttest results. The posttest results for the experimental class using the blended learning model and the control class using conventional (face-to-face) learning can be seen in Figure 3 below:

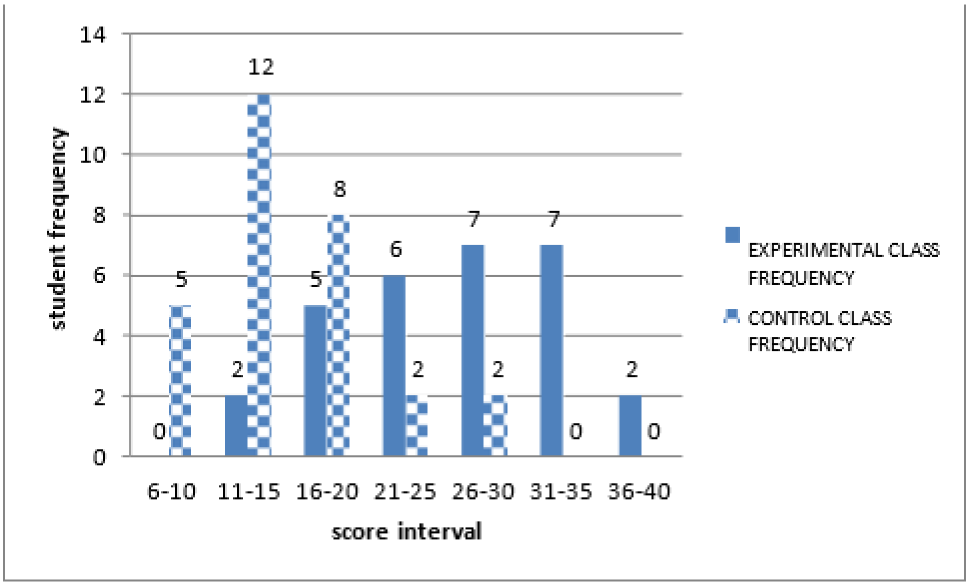

Figure 3 Bar Chart of Posttest Score Distribution of Critical Thinking Skills

Figure 3 shows the distribution of posttest scores for students in each interval for the control and experimental classes, with a maximum score of 40 (a total of 10 items). The score range of 6–10 was achieved by 0 students in the experimental class and 5 students in the control class. The score range of 11–15 was achieved by 2 students in the experimental class and 12 students in the control class. The score range of 16–20 was achieved by 5 students in the experimental class and 8 students in the control class. The score range of 21–25 was achieved by 6 students in the experimental class and 2 students in the control class. The score range of 26–30 was achieved by 7 students in the experimental class and 2 students in the control class. The score range of 31–35 was achieved by only 7 students in the experimental class. The score range of 36–40 was achieved by only 2 students in the experimental class.

The highest posttest scores were in the control class in the 26–30 interval, with a frequency of 2 students, and in the experimental class, 36–40, with a frequency of 2 students. The lowest posttest scores were for the control class in the 6-10 interval with 5 students, and for the experimental class in the 11-15 interval with 2 students.

Based on statistical calculations, several values of central tendency and dispersion of the data were obtained from the posttest scores, as shown in Table 6 below.

Table 6. Measures of Centralization and Distribution of Posttest Data Results

Data Centering and Distribution	Experimental Group	Control Group
Lowest Score	15	8
Highest Score	37	30
Mean	26,448	15,655
Median	26	15
Mode	20	10
Standard Deviation	6,294	5,300

Table 6 shows that the lowest score obtained by the experimental class was 15 and the control class was 8. While the highest score in the experimental class was 37 and the control class was 30. The average score obtained by the experimental class was 26.448 and the control class was 15.655. The median obtained by the experimental class was 26 and the control class was 15. The mode obtained by the experimental class and the control class were 20 and 10, respectively. The standard deviation in the experimental class was 6.294 and in the control class was 5.300.

3.3. Improving Students' Critical Thinking Skills

The improvement of critical thinking skills can be obtained by using the N-gain formula. The N-gain value in each class is obtained from the average N-gain score obtained by students in each class through calculating the difference between the posttest score and the pretest score compared with the difference between the ideal score and the pretest score so that the N-gain value is obtained for each student in the experimental class and the control class. Table 7 is a table of the average N-gain results for the experimental class and the control class.

Table 7. Average Results of N-gain Calculations for the Experimental Class and Control Class

Class	N-gain	Description
Experiment	0.63	Medium
Control	0.33	Medium

The improvement per indicator in students' critical thinking skills was obtained from the average N-gain score of students in each class, namely the experimental class and the control class. This is shown in Table 8 below.

Table 8. Average N-gain Indicators of Experimental Class and Control Class

No	Indicator	N-Gain			
		Experiment	Category	Control	Category
1	Answering clarification questions	0.43	Medium	0.13	Low
2	Assessing the credibility of sources based on the ability to provide reasons	0.68	Medium	0.56	Medium
3	Making decisions and judging value judgments based on facts	0.66	Medium	0.24	Low
4	Interacting with others: applying logical strategies	0.70	Medium	0.30	Low

Table 8 shows the average N-gain score for the experimental class on the indicators of answering classification questions of 0.43 in the medium category, assessing the credibility of a source of 0.68 in the medium category, making decisions and determining the results of considerations of 0.66 in the medium category, and interacting with others of 0.70 in the medium category. The average N-gain score for the control class on the indicators of answering classification questions of 0.13 in the low category, assessing the credibility of a source of 0.56 in the medium category, making decisions and determining the results of considerations of 0.24 in the low category, and interacting with others of 0.30 in the low category.

3.3. Statistical Analysis Prerequisite Test Results

A normality test was conducted to determine whether the data were normally distributed. The normality test was applied to two sets of data: the pretest and posttest of the experimental and control classes. The Shapiro-Wilk test was used to test the normality of these two sets of data using Statistical Product and Service Solutions (SPSS) software. Data were normally distributed if the sig. value was > 0.05 (5%), then H0 was accepted. The results of the normality test for both sets of data, namely the pretest and posttest of the experimental and control classes, can be seen in Table 9.

Table 9. Results of the Calculation of the Normality Test for the Pretest and Posttest of the Experimental Class and the Control Class

Statistic	Experiment Class (Pretest)	Control Class (Pretest)	Experiment Class (Posttest)	Control Class (Posttest)
Sig. (2-tailed)	0.067	0.056	0.135	0.438
Significance Level (α)	0.05	0.05	0.05	0.05
Conclusion	Data are normally distributed	Data are normally distributed	Data are normally distributed	Data are normally distributed

Based on the Shapiro-Wilk normality test, the pretest and posttest sig. values were obtained for the experimental and control classes at a significance level of 0.05. The conclusion drawn from the normality hypothesis testing criteria is that if sig. > 0.05, H0 is accepted, indicating that the data are normally distributed. Table 4.5 shows that both classes obtained sig. pretest and posttest sig. values greater than the significance level (0.05), thus concluding that the data are normally distributed.

A homogeneity test was conducted to determine whether the two classes had homogeneous (equal) critical thinking skills. The homogeneity test for pretest and posttest results used the Levene's test with the help of Statistical Product and Service Solutions (SPSS) software. Both pretest and posttest data for the experimental and control classes were declared homogeneous or similar if the sig. value was ≥ 0.05, indicating that H0 was accepted, indicating that the data had the same variance (homogeneous). The results of the pretest and posttest data homogeneity test for the experimental and control classes are shown in Table 10.

Table 10. Results of the Calculation of the Homogeneity Test for the Pretest and Posttest of the Experimental Class and the Control Class

Statistic	Pretest (Experiment Class and Control Class)	Posttest (Experiment Class and Control Class)
Sig.	0.186	0.787
Significance Level (α)	0.05	0.05
Conclusion	Both classes are homogeneous	Both classes are homogeneous

Based on the prerequisite tests for statistical analysis, it was found that the pretest and posttest data were normally distributed and had the same variance (homogeneous). Therefore, the hypothesis testing used parametric statistical analysis in the form of a T-test using SPSS software. The results of the pretest and posttest hypothesis testing can be seen in Table 11 below.

Table 11. Results of Pretest and Posttest Hypothesis Test Calculations

Test	Pretest Result	Posttest Result
Sig. (2-tailed)	0.68	0.001
Significance Level (α)	0.05	0.05
Conclusion	H_0 accepted	H_1 accepted

Based on the hypothesis test using the T-test at a significance level of 0.05, the sig. (2-tailed) value of the pretest and posttest results from both classes was obtained. The conclusion was drawn based on the provisions of hypothesis testing, namely if sig. (2-tailed) > 0.05 then H0 is accepted and H1 is rejected and if sig. (2-tailed) < 0.05 then H0 is rejected and H1 is accepted. Table 4.7 shows that the sig. (2-tailed) value of the pretest results data is above the significance level (0.05), which is 0.680 so it can be concluded that there is no difference in the average pretest of students' critical thinking skills in the experimental class and the control class. While the sig. (2-tailed) value of the posttest results data is below the significance level (0.05), which is 0.001 so it can be concluded that there is a difference in the average posttest of students' critical thinking skills in the experimental class and the control class.

The results of the questionnaire data obtained from the experimental class that was given learning treatment using the Blended Learning model assisted by Google Classroom were then processed based on each indicator to produce data in the form of percentages and then interpreted in the form of information on student interest in the Blended Learning model. The results of student responses to the Blended Learning model assisted by Google Classroom can be seen in Table 12 below.

Table 12. Student Interest Responses to the Blended Learning Model Assisted by Google Classroom

Indicator	Synchronous	Category	Asynchronous	Category	Blended Learning	Category
Attitude	70.75%	Very Good	61.67%	Very Good	66.21%	Very Good
Interest	79%	Very Good	65%	Very Good	72%	Very Good
Understanding	67%	Very Good	61%	Very Good	64%	Very Good
Average Total	72.25%	Very Good	62.55%	Very Good	67.40%	Very Good

Table 12 shows that the application of the Google Classroom-assisted Blended Learning model in the physics learning process on the concept of optical instruments resulted in a majority of students responding positively or showing interest, with an average score of 67.40%.

This study was conducted to determine the effect of the blended learning model on students' critical thinking skills in the optical instruments topic. This research aligns with the national education goal of developing thinking skills, one of which is critical thinking. Based on the average pretest scores obtained by each class, they were still below the ideal score (4 out of 40), with the average pretest results for the experimental and control classes being 3.38 and 3.59, respectively. Both classes had very low critical thinking skills. This was due to students' lack of familiarity and training in answering questions requiring critical thinking skills, and the learning approach did not emphasize individual student involvement, thus preventing students from engaging in in-depth physics study to achieve maximum results. Furthermore, learning that still uses conventional methods cannot accommodate individual differences, especially with the large number of students in one class, limited student attention, and theoretical content that requires in-depth understanding. As a result, the learning process tends to be oriented towards the imposition method, meaning that during the lesson, teachers simply convey the material by explaining what they deem important to the students. This is supported by previous research that suggests teachers are underutilizing internet facilities in schools and still using conventional learning methods, necessitating alternative and innovative learning [29], [30].

The critical thinking skills of students in both classes improved after being given different treatments. The experimental class was given learning capabilities using the Blended Learning model assisted by Google Classroom, while the control class received conventional (face-to-face) learning with a scientific approach. Students' critical thinking skills can be seen from the posttest results using the same questions as the pretest. The posttest results showed that the critical thinking skills of students in the experimental class increased to an average score of 26.44. Meanwhile, the critical thinking skills of students in the control class increased to an average score of 15.56. Although the final skills of both classes increased, the final skills of the experimental class were greater than those of the control class, which were 1.6 times the final skills of the control class. The higher results of the final abilities of students in the experimental class compared to the control class were due to several factors, including: 1) Trained students' abilities in constructing their knowledge in understanding physics in depth during learning and 2) the enthusiasm and interest of students in the experimental class during the learning process. This is reinforced by the results of previous research which produced data that the pretest and posttest results of the control and experimental classes showed a significant increase in students' critical thinking skills with blended learning [31], [32].

The application of the Blended Learning model with a flipped classroom approach (independent asynchronous activities) involved students in constructing their own knowledge before participating in face-to-face learning, using teaching materials accessible anytime through Google Classroom. During synchronous classroom activities, students actively participated in delivering and listening to presentations, discussions, and collaborated with other group members to formulate solutions to problems on the Student Worksheets. Students were not merely listeners during physics lessons, and they did not feel bored.

The increase in critical thinking skills in the experimental class was 0.63, categorized as moderate, while in the control class it was 0.33, categorized as moderate. Both the experimental and control classes experienced similar increases in critical thinking skills. Compared to the increase in critical thinking skills in the control class, the experimental class experienced twice the increase in critical thinking skills in the control class. The low increase in critical thinking skills in the control class was due to students' lack of training in developing critical thinking skills during the learning process. Students only received information or knowledge conveyed by the teacher, thus not optimally developing their critical thinking skills. The higher improvement in critical thinking skills of students in the experimental class compared to the control class was due to the use of the Blended Learning model, supported by Google Classroom, during the learning process, which positions students as both subjects and objects of learning and accommodates individual differences.

The experimental class, using the Blended Learning model, involved students in two learning activities: independent asynchronous and direct synchronous (face-to-face). Independent asynchronous learning was implemented by requiring students to construct their own knowledge through independent study using teaching materials accessible anytime through Google Classroom and taking online quizzes as a prerequisite for participating in face-to-face class. Direct synchronous learning reinforced students' knowledge, and students applied the knowledge gained during the independent asynchronous learning process [33], [34]. Meanwhile, in the control class, which used conventional learning with a scientific approach, students were not actively involved, only listening to the teacher's explanations, and only a few students participated in the question-and-answer session at the end of the lesson. Students were not accustomed to optimally processing their knowledge during the learning process.

The results of the hypothesis test obtained a significant value. (2-tailed) of 0.001 (sig. (2-tailed) ≤ 0.05). resulting in the interpretation that $H0$ is rejected and $H1$ is accepted. The conclusion of the statistical hypothesis, there is a significant influence on students' critical thinking skills after being given treatment of the application of the Blended Learning model in the experimental group compared to students in the control group. The results of this study are supported by other studies which reveal that learning with the Blended Learning model can improve conceptual understanding and reasoning in physics material, as well as train students to be independent and active. So it can maximize student learning outcomes [35], [36].

In addition, 80% of students in the experimental class found it easier to understand the concept of optical instruments after using the Blended Learning model. This is in line with previous research, which found that technology-integrated learning can improve students' conceptual understanding and problem-solving skills

[37], [38]. Furthermore, students in the experimental class were enthusiastic and interested in learning the concept of optical instruments during the learning process. This was evident in the results of the student response questionnaire related to the Blended Learning model assisted by Google Classroom, which was 67.40%, indicating that most students were interested in learning using this Blended Learning model. This is also in line with previous research that Blended Learning can increase student motivation [39], [40].

This Blended Learning model learning has several limitations, including: 1) this study only examined the material of optical instruments, so it cannot be generalized to other materials 2) learning with the Blended Learning model requires stable internet access for both students and teachers, so they must have adequate internet quota and wifi. 3) control of the research subject's abilities only includes direct synchronous learning (face to face) on the Blended Learning model variable and critical thinking skills. Independent asynchronous activities are not fully controlled, only emphasizing the honest attitude of students when providing information that they have carried out independent asynchronous learning before ending with a pretest as a prerequisite for participating in direct synchronous learning activities (face to face) in class.

4. CONCLUSION

The implementation of physics learning through the Blended Learning model assisted by Google Classroom has proven effective in enhancing conceptual understanding, fostering critical thinking skills, and strengthening learning motivation through students' active engagement in technology-based learning. The implication is that integrating Google Classroom can serve as a pedagogical strategy to improve digital literacy and the overall quality of learning in the digital era. For future research, this model should be tested across different topics and learning contexts to examine the consistency of its effectiveness.

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