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Exploration of Increasing Students' Critical Thinking in the Guided Discovery Learning Model on Light Waves

Syarifah Zahra and Iwan Permana Suwarna*
Physics Education/Faculty of Pedagogy and Education Science
Universitas Islam Negeri Syarif Hidayatullah, Jakarta, Indonesia
*Iwan.permana.suwarna@uinjkt.ac.id

Abstract

This study explored increasing students' critical thinking in the guided discovery learning model on light waves at one of the high schools in South Tangerang City. The research design employed a quasi-experimental nonequivalent control group design with students from class XI IPA 3 as the experimental group and class XI IPA 5 as the control group. Data was collected using a pretest and posttest instrument comprising ten essay questions and was analyzed using the n-gain method. The N-gain analysis indicated a significant improvement in critical thinking skills, with a score of 0,60 for the experimental group and 0,25 for the control group. This study concludes that using the guided discovery learning model effectively enhances students' critical thinking skills in light waves at one of the high schools in South Tangerang City. The implications of this study indicate that implementing the guided discovery learning model in teaching light wave material is highly relevant for enhancing students' critical thinking abilities. This approach enables students to actively engage, analyze information, and solve problems, thereby fostering the development of their critical thinking skills. By acquiring critical thinking skills through guided discovery learning, students become better prepared to tackle complex challenges and support integrating critical thinking development into diverse subjects within the curriculum.

Keywords: Critical Thinking Skill; Guided Discovery Learning model; Light Waves

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INTRODUCTION

In Indonesia, especially in high school, critical thinking skills are among the competencies students must acquire. Critical thinking enables students to analyze and evaluate information effectively. (Anjaniputra, 2020; Misbah et al., 2022; Utami et al., 2019; Yani et al., 2021). High school students in Indonesia still need to increase their critical thinking abilities. This is evident from a study using Partial Credit Models (PCM), which revealed that only 1.67 % of the participants had high critical thinking abilities, 60% of those surveyed had moderate abilities, and 3.33% had low abilities (Asysyifa et al., 2019). Several factors contribute to students' low critical thinking skills, including the instructors' inability to recognize the need to increase these skills (Benyamin et al., 2021; Yasir, 2020). Teachers prioritize the acquisition of subject-matter comprehension, even while trying to encourage critical thinking skills within an educational environment. Moreover, the deficiency in students' critical thinking skills can be ascribed to the utilization of teaching models that primarily prioritize the role of the teacher, resulting in limited active engagement of students in the process of exploring and comprehending problem-solving concepts (Khalid et al., 2021; Sunarya Amijaya et al., 2018). Hence, teachers must use instructional methods that actively engage students in the learning process while also requiring a change in teachers' perspectives and approaches toward developing the cultivation of critical thinking skills.

According to Markus (2019), Indonesia's placement on the Program for International Student Assessment (PISA) is 64th out of 72 nations, signifying a rather weak performance in the domain of critical thinking abilities among students in Indonesia. Based on the findings of this study, it is evident that many Indonesian students encounter challenges when attempting to solve Higher Order Thinking Skill (HOTS) questions that demand critical thinking abilities. The challenges mentioned above are notably conspicuous within the domains of Waves and Optics. The findings of the national test (UN) conducted in Indonesia indicate a relatively low performance among students, particularly in critical thinking skills, with an average score of 44 out of 100. This deficiency is particularly evident in the area of light waves. In South Tangerang, the scores obtained by individuals span from 33 to 49 on a scale of 100 (Kementrian, 2019).

Previous studies have demonstrated that 77.1% of students struggle with analyzing concepts related to light refraction and reflection, and 60.87% struggle with solving mathematical problems in this context (Ainiyah et al., 2020). The findings from interviews conducted with teachers at SMAN 4 South Tangerang indicate that conventional teaching methods are still prevalent while emphasizing the need for increased student curiosity in physics. A survey questionnaire was given to 32 students enrolled in the 11th grade at SMAN 4 South Tangerang. The study's findings revealed that the teaching methods used by teachers do not motivate students, leading to a significant percentage of students needing help comprehending the application of formulas and resolving physics problems. Moreover, students often have difficulty when it comes to articulating their viewpoints.

Critical thinking skills need to be encouraged and improved in students. Students accustomed to critical thinking can engage in problem-solving and agree that the information they receive can serve as a convincing basis for solving problems (Haryandi et al., 2019; Khotimah & Nyeneng, 2017; Razak et al., 2022; Setiawan & Islami, 2020). Developing critical thinking abilities within learning environments will provide students with the necessary cognitive tools to develop as effective problem solvers, equipped with the capacity for sound reasoning and a balanced perspective when approaching difficult problems. (Rahmi et al., 2019; Razak et al., 2022; Syuhada et al., 2022). The lack of students' critical thinking skills will affect the efficiency of human resources. Without the necessary skills, Indonesia cannot produce graduates who satisfy the competency requirements and challenges of 21st-century skills. In addition, developing critical thinking skills is a fundamental component of the competencies required for active participation in society (Dam & Volman, 2004; Shevardnadze et al., 2021). This will lead to a situation where future generations will require assistance to successfully deal with the variety of challenges they are likely to encounter. Students' low achievement on light waves needs to be addressed promptly. If left unattended, the low achievement in critical thinking skills related to light waves will continue in the following academic years. The teaching models and supporting learning media users must be more interactive and help students grasp abstract physics concepts (Neves et al., 2013; Oktaweri et al., 2019; Rahmi et al., 2019). Disregarding this matter will challenge students when comprehending abstract concepts in physics.

Using appropriate and innovative teaching models, such as guided discovery learning, is one way to address students' low levels of critical thinking skills (Priadi et al., 2021; Syuhada et al., 2022). Guided discovery learning is a teaching model that assists students in improving their critical thinking skills and gaining experience in discovering concepts from the problems they encounter through the exploration of information in a series of teacher-led scientific activities (Ahmad et al., 2021; Atiyah et al., 2020; Handayani et al., 2017; Pratiwi et al., 2022; Mustofa, 2019). A study found that implementing guided discovery learning effectively improves students' higher-order thinking skills, proving that guided discovery learning enhances students' critical thinking skills (Nofiana & Prayitno, 2020; Ramadan et al., 2021).

Guided Discovery Learning is ideally suited for implementation in physics, particularly concerning the concept of light waves. Light waves have abstract properties and can be difficult to comprehend through direct instruction alone. Guided Discovery Learning provides students with opportunities for exploration and self-discovery, enabling them to understand light waves' constitutions and properties better. Moreover, students are allowed to conduct experiments and directly observe light-wave phenomena. (Arafah, 2020; Uskenat & Adelia, 2021). Students are presented with challenges or problems that they must solve through exploration and discovery in Guided Discovery Learning. This encourages students to utilize their critical thinking and problem-solving skills in real-world scenarios. In light waves, students may face challenges such as comprehending the dispersion of light by a prism or calculating the wavelength using the appropriate formulas. This aids students in developing their analytical and logical reasoning skills. (Kasmiana et al., 2020; Rahmadi et al., 2019; Tobing & Siregar, 2016).

The current study concentrates specifically on light waves. In contrast to existing research that takes a more general approach to investigating critical thinking in the field of physics, this study aims to delve thoroughly into specific critical thinking skills in the context of light waves. In addition, the study employs the guided discovery learning model, which engages students in actively exploring and discovering knowledge under the supervision of a teacher. Based on Tiruneh's framework of critical thinking indicators, a research instrument will be developed to assess students' critical thinking skills regarding light waves. Therefore, this study aims to shed new light on the effectiveness of the guided discovery learning model in fostering students' critical thinking skills in the domain of light waves.

METHOD

This research utilizes the quasi-experimental method with a nonequivalent control class design (Shadish et al., 2002). In this design, two classes (experimental and control classes) are not randomly selected. The researcher conducts a pretest as an initial step to assess the student's level of critical thinking abilities and identify the experimental and control classes (Sugiyono, 2013). After the treatment is completed, the researcher administers a posttest to measure the improvement in the two classes' students' critical thinking abilities. The research design table used can be seen in Table 1

Table 1 Research design

Class	Pretest	Treatment	Posttest
Experimental	O_1	X	O_2
Control	O_3	X_1	O_4

(Sugiyono, 2013)

During the first semester of the 2022/2023 academic year, this investigation was conducted at one of the high schools in South Tangerang City. The investigation was conducted over one month, from February to March, and included six meetings. The study population was 195 grade 11 science students enrolled in one of the SMAN Kota Tangerang schools. Researchers determined samples using purposive sampling techniques, taking special considerations into account. The selection of samples was based on teacher recommendations and average pretest scores. Consequently, the experimental group was comprised of 38 class XI IPA 3 students who received guided discovery learning treatment. Compared to the experimental group, the control group consisted of 38 students from class XI IPA 5 who did not receive any treatment and followed the standard teaching paradigm employed by the school's teachers.

This study's collection technique consisted of a pretest and posttest instrument. Experts in construct, content, and language validated the instrument, which consists of ten essay questions and was devised based on Tiruneh's indicators of critical thinking. Five aspects of reasoning, hypothesis testing, argument analysis, likelihood and uncertainty analysis, and problem-solving and decision-making were used to measure the indicators of critical thinking (Tiruneh et al., 2017).

After collecting data with research instruments, the data would be processed and analyzed to answer the research questions and ensure the research hypotheses. Before conducting hypothesis testing, statistical prerequisites such as normality, homogeneity, and N-gain tests were conducted. This study's N-gain test was designed to measure the improvement in outcomes following administration of the treatment to both classes (Hake, s1999). The calculation of N-gain (Normalized Gain) values refers to the method proposed by Hake, with the following categories:

Table 2 Categories of N-gain index

Range	Criteria
$NG \geq 0,70$	High
$0,30 \geq NG < 0,70$	Medium
$NG < 0,30$	Low

(Hake, 1999).

After conducting the prerequisite tests, the following stage tests the theory based on the criteria. This research will examine the hypothesis utilizing the Mann-Whitney U test with the assistance of IBM SPSS 25 software. In making decisions, use the following criteria:

a) If sig.$<\alpha$ (0,05), then H_0 is rejected and H_1 is accepted
b) If sig.$>\alpha$ (0,05), then H_0 is accepted, and H_1 is rejected.

RESULT AND DISCUSSION

This study investigated how to increase students' critical thinking in the guided discovery learning model for light waves. The collected data included the results of the control and experimental groups' pretest and posttests and N-gain measurements. Figure 1 displays the results of the critical thinking examination administered to the experimental and control groups of students before applying the experimental treatment.

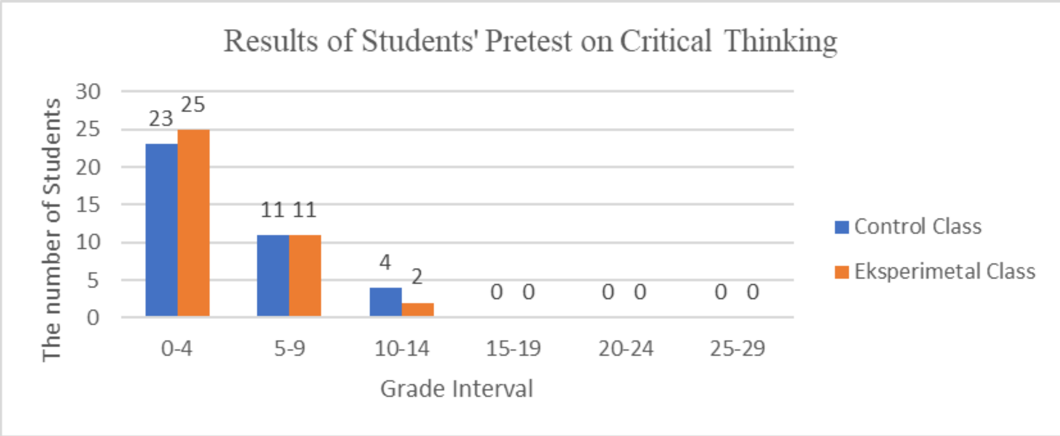

Figure 1 Bar chart of pretest results for control and experimental classes

Figure 1 shows the distribution of student scores in each interval for both the control and experimental classes. The results indicate that both classes have relatively low scores. Therefore, there are no significant differences between the experimental and control groups regarding test scores. Thus, both divisions begin with comparable abilities.

According to Tiruneh, Figure 2 demonstrates the percentage of pretest results for indicators of critical thinking for experimental and control classes.

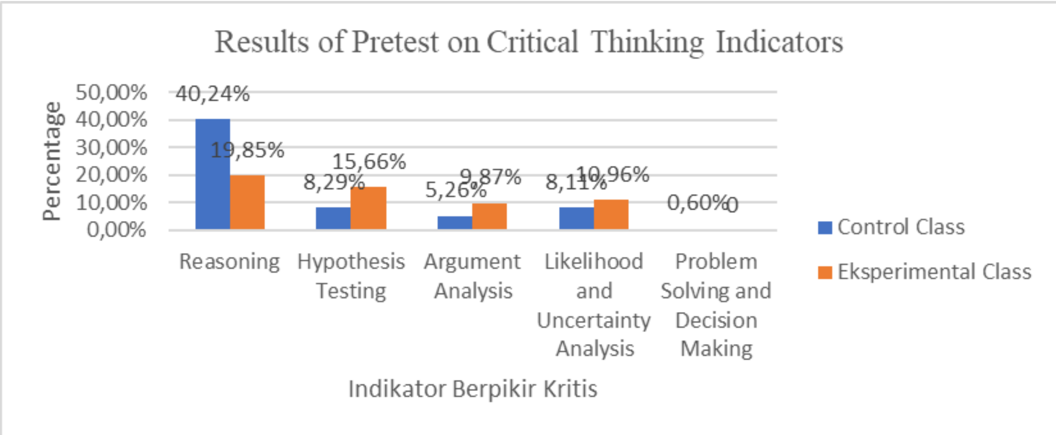

Figure 2 Pretest results of the control and experimental classes for each critical thinking indicator

Figure 2 presents the pretest results for each indicator of critical thinking for the experimental and control classes. The results indicate that the control class had the most students for each indicator. Based on the graph, the pretest results for both classes indicate that their critical thinking skills were comparable, as there was no statistically significant difference between their scores.

Figure 3 displays the posttest results obtained by the control and experimental groups following treatment in this study.

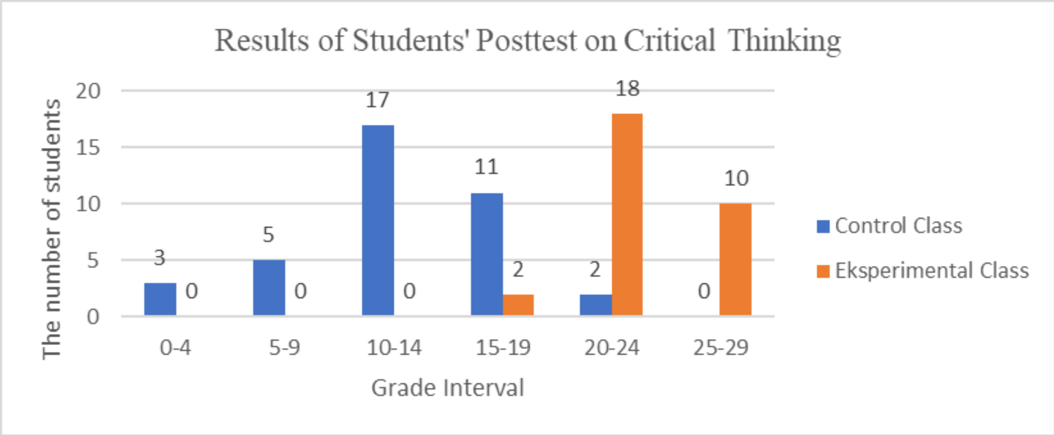

Figure 3 Bar diagram of posttest results for control and experimental classes

The distribution of student scores in each interval for the control and experimental groups is depicted in Figure 3. Two students in the control group received the greatest score within the interval 20–24, while ten students in the experimental group had the highest score within the interval 25–29. Three students in the control group had the lowest score in the interval 0–4, while two students in the experimental group had the lowest score in the interval 15–19. These results indicate a disparity between the scores of the control and experimental groups, indicating that the ultimate abilities of the two classes were distinct.

The summary of the percentage of posttest results for critical thinking indicators for the control group and the experimental group, according to Tiruneh, can be seen in Figure 4.

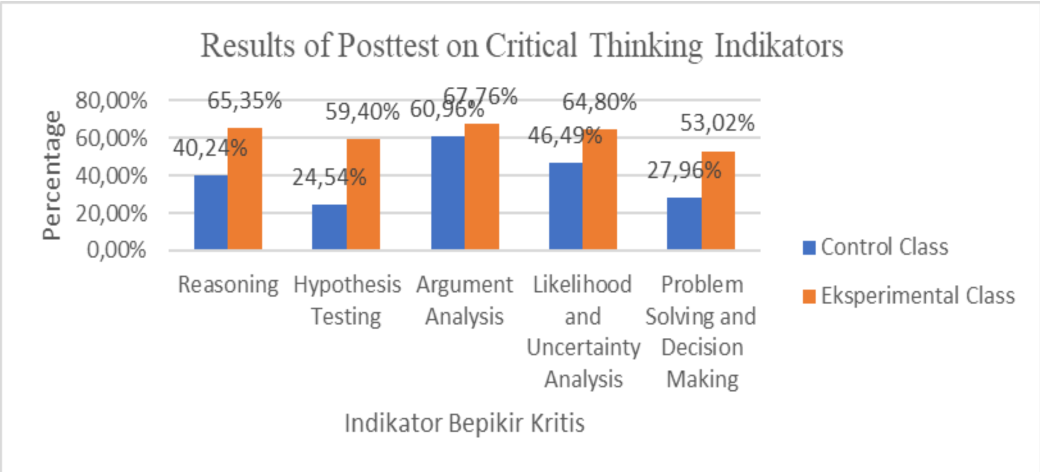

Figure 4 Posttest results of control and experimental classes on each critical thinking indicator

The bar chart in Figure 4 summarizes the percentage of posttest results for each indicator of critical thinking for the control and experimental classes. The results indicate that the experimental group had the highest proportion of critical thinking indicators for each indicator. Based on the chart, the posttest results for both classes demonstrate a significant difference, leading to the conclusion that the final critical thinking ability of the two classes differs.

The average N-gain values determined the improvement in critical thinking among students in both sections. The N-gain results for the control and experimental groups are shown in Table 3.

Table 3 Average N-gain results for the control and experimental classes

Class	N-gain	Explanation
Control Class	0.25	Low
Experimental Class	0.60	Moderate

The average N-gain values for the experimental and control groups are presented in Table 3. Based on the N-gain values, it can be concluded that guided discovery learning results in greater development of critical thinking skills than traditional learning. Table 4 displays the improvement in both classes' critical thinking indicators based on the average N-gain.

Table 4 Average N-gain results for critical thinking indicators

Indicators of Critical Thinking	N-Gain			
	Control Class	Explanation	Experimental Class	Explanation
Reasoning	0.12	Low	0.61	Moderate
Hypothesis testing	0.16	Low	0.59	Moderate
Argument analysis	0.28	Low	0.62	Moderate
Analysis of possibilities and uncertainties	0.29	Low	0.49	Moderate
Problem-solving and decision-making	0.39	Moderate	0.71	High

Table 4 shows the variance in the average N-gain increase for each indicator of critical thinking between the two classes. The experimental class showed the greatest increase for the problem-solving and decision-making indicator, 0.71 or 71%. In contrast, the control group showed the smallest increase in the reasoning indicator, 0.12 or 12%. These results indicate that students' critical thinking improved more in the experimental than in the control class.

Normality tests were conducted on the pretest and posttest for both classes. This test was performed using the SPSS Statistics 25 software with the Shapiro-Wilk test. The test results can be seen in Table 5.

Table 5 Normality test results for pretest and posttest in the control and experimental classes

	Pretest		Posttest	
	Control Class	Experimental Class	Control Class	Experimental Class
Sig.	0.001	0.019	0.028	0.007
Shapiro Wilk Test	Sig.< 0.05 = is rejected			
The decision	Non-normality distributed data			

The Shapiro-Wilk normality test stipulates that if Sig.0.05, H0 is accepted, indicating that data are normally distributed. If Sig.0.05, H0 is rejected, indicating that the data do not follow a normal distribution. Table 5 displays the data for both classes' pre- and posttest with values less than 0.05. Therefore, it can be concluded that the pretest and posttest data for both classes did not follow a normal distribution.

The data from both classes' pretest and posttest were subjected to homogeneity testing. This ANOVA test was conducted using the SPSS Statistics 25 software. Table 6 displays the outcomes of the homogeneity test.

Table 6 Presents the results of the homogeneity test for the pretest and posttest data

	Pretest	**Posttest**
Sig.	0.579	0.001
ANOVA test	Sig. ≥ 0.05 = H_0 is accepted	Sig. < 0.05 = H_0 is rejected
The decision	Homogeneous data	Non-homogeneous data

The criteria for homogeneity testing state that if Sig.≥0.05, H_0 is accepted, indicating that the data is homogeneous. If Sig.<0.05, H_0 is rejected, indicating that the data is not homogeneous. Table 6 shows that the pretest data is homogeneous, while the posttest data is not homogeneous.

Hypothesis testing was performed using the SPSS Statistics 25 software. Since both classes' pretest and posttest data are not normally distributed, the Mann-Whitney U test was used for hypothesis testing. The results of the hypothesis testing can be seen in Table 7.

Table 7 Presents the results of the hypothesis for the pretest and posttest data the control class and experiment class

	Pretest	**Posttest**
Sig. (2-tailed)	0.825	0.001
Uji Mann Whitney U	Sig. ≥ 0.05 = H_0 is accepted	Sig. < 0.05 = H_0 is rejected
The decision	H_0 is accepted	H_0 is rejected

The hypothesis testing criteria state that if Sig.≥0.05, H_0 is accepted, indicating no influence of the guided discovery learning model on students' critical thinking skills on the topic of light waves. If Sig.<0.05, H_0 is rejected, demonstrating how the guided discovery learning paradigm affected how students thought critically about the topic of light waves. Table 5 shows that the pretest data is above 0.05, and the posttest data is below 0.05. Therefore, it can be said that the guided discovery learning paradigm has an impact on student's critical thinking abilities in the area of light waves.

Initial student critical thinking abilities are still relatively modest. Pretests and posttests were used to measure these abilities. The lowest score obtained by both groups was 2, while the maximum score for the control group was 12, and for the experimental group, it was 10. These statistics indicate that the scores in both courses continue to be deemed inadequate. This finding is consistent with the 2019 National Examination on Light Waves results, which revealed that students continue to struggle with queries requiring critical thinking indicators (Kementrian et al., 2019). Students' deficient critical thinking skills can be attributed to unfavorable environmental and situational factors. One of the contributing factors is the learning paradigm employed by teachers, which discourages student participation. The development of students' critical thinking skills can be hindered by learning models that exclusively emphasize knowledge and view them as passive recipients. According to student interviews, the predominant learning model is centered on the teacher, with materials written on the blackboard or presented using PowerPoint. This learning model is too monotonous for students, resulting in a lack of motivation to study. Consequently, many students require assistance comprehending abstract concepts, utilizing formulas, and solving physics problems.

Based on the pretest results for each critical thinking indicator, students' initial abilities were categorized as low. In both experimental and control courses, the reasoning indicator was below 25%, indicating that students could not identify errors in light refraction data, calculate the deviation angle formula, and interpret experimental results in cases of light polarization. The percentage of student’s ability as measured by the indicator for testing hypotheses was also low, ranging around 7-8%. Students had to develop essential skills in interpreting the relationship between variables in light dispersion experiments; observation tables of light diffraction could not be used to derive conclusions. Approximately 4 to 5 percent of the students’ argument analysis ability was also substandard. They could not evaluate arguments by evaluating the generalizability of diffraction and polarization lattice diagram generalizations. On the indicator for probability and uncertainty analysis, the students' percentage of aptitude ranges between 9 and 10%. In Young's double-slit experiment, students cannot foresee and argue the probabilities of events.

Indicators of problem-solving and decision-making indicate that the student's problem-solving and decision-making skills were approximately 0-0.6% below average. Light polarization problems and Young's double-slit experiment require assistance in recognizing problem characteristics, resolving problems, and providing alternative solutions. This is consistent with previous studies indicating that students' critical thinking skills fall within the moderate range, and students need to become more acclimated to questions that test these skills (Afriana et al., 2021; Arini & Juliadi, 2018; Rahmawati & Masykuri, 2020). As a result, when students encounter difficulties answering questions, they are reluctant to continue solving them (Anggraeni et al., 2023; Arini & Juliadi, 2018).

Students' final critical thinking abilities in the control and experimental sections differ significantly. The distribution of posttest scores in both courses demonstrates this (Figure 3). The use of the guided discovery learning model in the experimental class led to the discrepancy in posttest scores. The control group, in contrast, only used the conventional learning model that physics instructors typically use. Due to the monotonous conventional model for students, which inhibited the development of their critical thinking skills, the lowest score in the control class still needed to be increased. The experimental and control courses significantly differed, indicating that learning improved critical thinking abilities. This is supported by the findings of previous researchers, who demonstrated that students who followed the guided discovery learning model had a substantial increase in their conceptual understanding of physics compared to those who did not. (Arafah, 2020; Kasmiana et al., 2020; Sahara et al., 2020).

The influence of the guided discovery learning model on the learning process is one of the factors contributing to developing these critical thinking skills. Guided discovery learning requires students to engage in critical thinking, information analysis, and decision-making based on pertinent evidence or arguments. This learning model enables students to conceptualize the material through direct interaction with the learning content. Due to the use of a monotonous learning model, the critical thinking skills of the control class did not develop. The teacher-centered, conventional learning model fails to provide stimuli that elicit positive responses from students, making it more difficult for them to overcome problems related to light waves. This is consistent with prior research indicating that students require innovative and effective learning models, such as guided discovery learning (Priadi et al., 2021; Jayanto et al., 2019).

N-gain (Table 4) demonstrates that, based on the collected data, each of the indicators of critical thinking in the experimental group demonstrated significant improvement. Regarding the problem-solving and decision-making indicators, the experimental class demonstrated the greatest improvement (71%) compared to the control group (39%). This was because guided discovery helped students develop problem-solving abilities. Through the exploration phase, students were encouraged to confront problems or challenges requiring innovative thought, alternative solutions, and evidence-based evaluation. From the first to the fourth meeting, students were consistently trained in the exploration stage, allowing them to develop their abilities to formulate and solve mathematical problems critically. 67% of students identified the problem by answering, "Why does the interference pattern not produce a sequence of bright and dark fringes? When presented with a diagram of Young's double-slit interference experiment. After identifying the problem, the students were able to provide a solution by asserting, "We need to replace the wider slit through which the incident light passes with a narrower slit."

The experimental group's probability and uncertainty analysis indicator exhibited the least improvement, at 49%, compared to the control group's 28%. Due to time constraints in each meeting, students could only analyze the probability and uncertainty of the provided data via worksheets. Therefore, students could practice at home to comprehend how they would approach probability under the given conditions, but few were willing. Each indicator improved significantly more in the experimental and control classes. This is because students in the experimental class were more interactive when using the guided discovery learning model than those in the control class, which utilized only conventional learning models. Based on interviews, students in the control group felt that they were not involved in the learning model. They tended to observe the provided materials and example questions passively. When given a question, they would search for answers on other websites without knowing the validity of the information.

In contrast, students in the experimental class were excited to learn and viewed the group practicum as highly helpful. They were always willing to conduct experiments, identify problems, and discover solutions to the problems presented to them. This is consistent with previous research indicating that implementing guided discovery learning models results in a 27.30% improvement in students' critical thinking abilities (Hidayatul et al., 2020; Nursidah et al., 2019).

The posttest statistical hypothesis test results indicate that H_0 was rejected while H1 was accepted. The statistical hypothesis test concludes that there was a difference between the control and experimental classes' final critical thinking scores. Based on the increase (N-gain) in each indicator of critical thinking, the effect of guided discovery learning models on students' critical thinking skills can be determined. These findings are supported by previous research indicating that guided discovery learning models have a positive and significant effect on critical thinking skills on each indicator and that it is essential to use this model to improve students' critical thinking skills (Priadi et al., 2021; Syaifulloh et al., 2022; Rulita & Jazuli, 2021).

CONCLUSION

According to research results, the guided discovery learning model influences the enhancement of students' critical thinking skills on the topic of light waves. Students in the experimental class improved their critical thinking skills with an N-gain score of 0.60 (moderate category). Every indicator of critical thinking skills improved, including reasoning (61%), testing of hypotheses (59%), argument analysis (62%), analysis of possibilities and uncertainties (49%), and problem-solving and decision-making (70%). Not only for the topic of light waves but also for a wider range of subjects, the guided discovery learning model is a viable option for the learning process. However, it is essential to note that this model requires a lengthier learning period, so effective time management is required. Additionally, students should be familiarized with the stages of this learning model beforehand to ensure that they are accustomed to the learning process.

The implications of this study indicate that implementing the guided discovery learning model in teaching light wave material is highly relevant for enhancing students' critical thinking skills. This approach enables students to actively engage, analyze information, and solve problems, thereby fostering the development of their critical thinking skills. By acquiring critical thinking skills through guided discovery learning, students become better prepared to tackle complex challenges and support integrating critical thinking development into diverse subjects within the curriculum.

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