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The Effectiveness of Discovery Learning in Enhancing Senior High School Students' Critical Thinking Skills on Heat and Temperature Topics

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Abstract

Teachers in 21st-century learning are expected to adapt their teaching to match the demands of that kind of learning. Critical thinking skills (CTS) are essential competencies in physics learning; however, many students still experience difficulties in anlyzing problems, evaluating information, and drawing conclusions, particularly in heat and temperature topics. Therefore, effective learning models are needed to improve students' critical thinking skills. This study aimed to determine the effectiveness of the Discovery Learning model in improving students' critical thinking skills on heat and temperature material. The study employed a quasi-experimental method using a non-equivalent control group design. The participants consisted of 31 students in the experimental class and 31 students in the control class. Data were collected through critical thinking tests and students response questionnaires and were analyzed using N-Gain and the Mann-Whitney U Test. The result revealed that the average n-gain score of the experimental class was 0,5647, while the control class obtained 0,3213, both categorized as moderate. The mann u test showed a significance value of less than 0,0001, indicating a significant difference between the two classes. In addition, student responses reached 82,5%, which was categorized as very good. These findings indicate that the Discovery Learning model is effective in improving students' critical thinking skills and can be considered an alternative learning model for physics instruction, particularly in heat and temperatur topics.

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INTRODUCTION

Science education plays a crucial role in developing students' critical thinking skills, particularly in understanding abstract concepts and complex natural phenomena (Annisa & Mufit, 2021). In physics education, critical thinking enables students to analyze information, evaluate evidence, draw logical conclusions, and apply scientific concepts to solve real-world problems (Saputri et al., 2024). One of the fundamental topics in senior high school physics is temperature and heat, which requires students to understand energy transfer, and changes in the state of matter (Jamaludin et al., 2022). In the Indonesian context, the implementation of the Merdeka Curriculum emphasizes the development of critical thinking as one of the core competencies (Abidin et al., 2024). According to the Ministry of Education and Culture (2023), approximately 65% of senior high school students struggle with physics concepts related to thermodynamics, particularly temperature and heat. However, previous studies have reported that many students experience difficulties in understanding these concepts conceptually and often rely on memorizing formulas rather than

constructing meaningful understanding (Jamaludin et al., 2022). As a result, students frequently struggle to apply their knowledge when confronted with contextual problems, highlighting the need for instructional approaches that actively engage learners and foster HOTS skills (Hakim et al., 2023).

Temperature and heat are among the physics topics that frequently lead to conceptual misunderstandings because students must relate microscopic and macroscopic phenomena while interpreting abstract thermal processes (Hakim et al., 2023). Critical thinking has been widely recognized as one of the essential competencies required in the twenty-first century (Helendra, 2025). It involves the ability to interpret information, analyze arguments, evaluate evidence, make reasoned judgments, and solve problems systematically, Ennis (1993, as cited in Helendra, 2025). Facione's (2010) framework identifies five core indicators of critical thinking: interpretation, analysis, evaluation, inference, and explanation. In physics education, these indicators are manifested when students interpret experimental data, analyze relationships between physical variables, evaluate the validity of scientific claims, and construct evidence-based explanations for natural phenomena. Within physics learning, critical thinking is particularly important because students are expected not only to understand scientific concepts but also to investigate phenomena, interpret data, and develop evidence-based explanations (Rahayu Gustika, Indra Sakti, 2018). Therefore, learning environments should be designed to encourage active participation and knowledge construction rather than passive reception of information (Sabarrini et al., 2024).

One instructional model that aligns with these principles is Discovery Learning (Prasetyo & Mulyani, 2025). Rooted in Bruner's constructivist theory, Discovery Learning emphasizes the active involvement of students in constructing knowledge through exploration, investigation, and reasoning processes (Bruner, 1961, as cited in Nurhadi, 2020). Through activities such as observing phenomena, formulating questions, collecting and analyzing data, testing hypotheses, and drawing conclusions, students are encouraged to discover concepts independently (Fitriani et al., 2022). The Discovery Learning model consists of six structured stages: (1) stimulation, where students are exposed to phenomena; (2) problem statement, where students formulate questions; (3) data collection, where students gather information through experiments; (4) data processing, where students analyze findings; (5) verification, where students test their hypotheses; and (6) generalization, where students draw conclusions. During this process, the teacher acts as a facilitator who guides students without providing direct answers. These learning experiences support the development of critical thinking skills by engaging students in analytical, evaluative, and reflective thinking processes (Dehong et al., 2020).

Previous studies have demonstrated the positive impact of Discovery Learning on students' critical thinking skills. (Nurroniah et al., 2025) reported that the implementation of Discovery Learning significantly improved students' critical thinking abilities with an effective category and N-Gain scores in the moderate criteria. Similarly, (Ridwan, 2021) found that Discovery Learning enhanced critical thinking skills from 77.33% (enough category) in Cycle I to 92,% (very good category) in Cycle III on the topic of temperature and heat (Ridwan, 2021). Furthermore, (Edi & Raden, 2021) revealed that the integration of Discovery Learning with differentiated instruction contributed to improvements in students' critical thinking skills, with posttest scores increasing from 48 to 78. These findings indicate that Discovery Learning has considerable potential to support the development of higher-order thinking skills across various science learning contexts (Supriyati, 2022).

Despite its advantages, the effectiveness of Discovery Learning may vary depending on the learning context, students' readiness, and teachers' ability to facilitate the discovery process. Limited instructional time, insufficient laboratory facilities, and students' dependence on teacher-centered instruction remain common challenges in its implementation (Yadi & Nirwana, 2023). In addition,

most previous studies have focused on topics such as electricity, waves, or general science concepts, while studies examining the effectiveness of Discovery Learning in improving critical thinking skills on the topic of temperature and heat remain relatively limited. This gap indicates the need for further investigation, particularly in senior high school physics learning contexts (Wafa & Jatmiko, 2022).

At SMA Negeri 1 Tirtayasa, physics instruction on temperature and heat is still predominantly delivered through expository teaching methods, where teachers play a dominant role and students tend to be passive recipients of information. Preliminary interviews with physics teachers revealed that students frequently experience misconceptions regarding heat transfer and heat capacity. These challenges are further compounded by the limited opportunities for students to participate in hands-on experimental activities. Therefore, the implementation of a more student-centered learning model is needed to address these issues and enhance students' critical thinking skills.

Based on the aforementioned considerations, this study aims to investigate the effectiveness of the Discovery Learning model in improving the critical thinking skills of eleventh-grade students on the topic of temperature and heat at SMA Negeri 1 Tirtayasa. Unlike previous studies that primarily focused on other physics topics, this study specifically investigates the effectiveness of Discovery Learning in improving students' critical thinking skills on the topic of temperature and heat through N-Gain analysis, Mann–Whitney U testing, and student response data (Quraisy & Madya, 2021). The findings are expected to contribute to the growing body of research on constructivist learning approaches and provide practical implications for improving physics instruction aimed to develop students' critical thinking skills.

RESEARCH METHOD

The research design used by the researcher is a type of quantitative research with a quasi-experimental design using a non-equivalent control group design.This is done to investigate causal hypotheses about cause-and-effect that can be manipulated by comparing one or more experimental groups that receive treatment with one comparison group that does not receive treatment (Supriyati, 2022). This research design is applied because it aligns with the research objective, which is to find out whether the discovery learning model is more effective in improving students' critical thinking skills. This study uses descriptive statistics such as mean, min, and max, as well as inferential statistics. The inferential statistics used are the Mann-Whitney U test. The research design shown below.

Table 1. Research Design

Group	Pre-test	Treatment	Post-test
Eksperiment	Y_1	X	Y_2
Control	Y_1	-	Y_2

(Supriyati, 2022)

In this research design, Y_1 represents the pre-test administered to both the experimental and control groups before the implementation of the learning intervention. The pre-test was conducted to measure students' initial critical thinking skills and to determine the equivalence of the two groups prior to treatment. X represents the instructional treatment provided exclusively to the experimental group, in which the Discovery Learning model was implemented throughout the learning process. This treatment was designed to engage students actively in discovering concepts through exploration, problem identification, data collection, data analysis, verification, and conclusion drawing. Meanwhile, the control group received conventional instruction without the implementation of the Discovery Learning model. After the instructional intervention was completed, Y_2 represents the post-test administered to both groups to evaluate students' critical thinking skills following the

learning process. The comparison between the pre-test and post-test scores, as well as the comparison between the experimental and control groups, was used to determine the effectiveness of the Discovery Learning model in improving students' critical thinking skills.

This research was conducted at SMA Negeri 1 Tirtayasa with the research subjects consisting of two classes, XI C and XI E each consisting of 31 students who were given a pre-test before receiving treatment and then were given treatment using the discovery learning model on the topic of temperature and heat. After the treatment, the same material was used for a post-test or final test.

The percentage scores obtained from the expert validation were interpreted using the following criteria: (80% < x ≤ 100%) Very Feasible, (60% < x ≤ 80%) Feasible, (40% < x ≤ 60%) Fairly Feasible, (20% < x ≤ 40%) Not Feasible, and (0% < x ≤ 20%) Very Infeasible.

The impact of the discovery learning model approach on students' critical thinking skills was assessed using the results of the post-test or final test. The study was conducted face-to-face. During the learning process, students were also trained in problem-solving skills found in the student worksheets. This study used a critical thinking skills instrument with five indicators: interpretation, analysis, evaluation, inference, and explanation (Edi & Raden, 2021).

$$N - Gain = \frac{skor\ posttest\ -\ Skor\ pretest}{Skor\ maksimum\ -\ Skor\ pretest} \quad (1)$$

After the N-Gain is known, it will then be classified for each student by calculating the average N-Gain score each student gets on each question. This way, the improvement in students' critical thinking skills can be seen based on the N-Gain score criteria.

The improvement in students' critical thinking skills was analyzed using the normalized gain (N-Gain) score. The N-Gain values were interpreted using the following criteria: scores were categorized as high (>0.70), moderate (0.30 to 0.70), and scores low (<0.30) (Cohen, 2013).

The experimental group received instruction through the Discovery Learning model, whereas the control group was taught using conventional lecture-based instruction. The implementation of Discovery Learning followed six stages: stimulation, problem statement, data collection, data processing, verification, and generalization. Throughout the learning process, students used Student Worksheets (LKPD) designed to guide them in observing phenomena, gathering information, analyzing data, engaging in group discussions, and drawing conclusions related to the topic of temperature and heat.

Two instruments were employed to collect the research data: a critical thinking skills test and a student response questionnaire. The critical thinking skills test served as the primary instrument to evaluate the effectiveness of Discovery Learning and consisted of 10 essay questions administered as both pretests and posttests. The test items were developed based on Facione's critical thinking indicators, namely interpretation, analysis, evaluation, inference, and explanation. Prior to implementation, the instrument underwent content validation through expert judgment involving two experienced physics teachers. The expert review evaluated the appropriateness of the instrument in terms of critical thinking skills, construction, and language and sentence structure (Zamanzadeh et al., 2015), following the recommendations proposed by Polit and Beck (2006). Based on the validators' evaluations, the instrument was deemed suitable for use after minor revisions.

Meanwhile, the student response questionnaire was used as supporting data to illustrate students' perceptions of the implementation of Discovery Learning. The questionnaire consisted of eight statements measured using a five-point (Suyati et al., 2022), namely very poor, poor, fair, good, and very good, and then analyzed descriptively using percentage scores.

The research procedure began with administering a pretest to both the experimental and control groups to determine students' initial critical thinking skills. Subsequently, the experimental

group participated in learning activities using the Discovery Learning model, while the control group received conventional instruction. Upon completion of the instructional sessions, both groups were given a posttest. Finally, the student response questionnaire was distributed to students in the experimental group. Data were analyzed using both descriptive and inferential statistics with the assistance of IBM SPSS Statistics software. Descriptive statistics were used to summarize the pretest and posttest results as well as students' responses to the questionnaire. The improvement in students' critical thinking skills was analyzed using the Normalized Gain (N-Gain) test. Furthermore, differences in the improvement of critical thinking skills between the experimental and control groups were examined using the Mann–Whitney U test at a significance level of <0.05. The results of these analyses were used to determine the effectiveness of the Discovery Learning model in enhancing students' critical thinking skills on the topic of temperature and heat.

RESULTS AND DISCUSSION

The critical thinking skills test used in this study was first analyzed to determine its feasibility as a research instrument. the validation process aimed to evaluate the appropriateness of the instrument in terms of critical thinking skills indicators, construction, and language and sentence structure. The results of the expert validation are presented in Table 2.

Table 2. Results of Expert Validation of the Critical Thinking Skills Test Instrument

Assessment Aspects	Validator 1 (%)	Validator 2 (%)	Mean (%)	Category
Critical Thinking Skills	96,00	92,00	94,00	Very Feasible
Construction	100,00	100,00	100,00	Very Feasible
Language & Sentences Structure	96,00	96,00	96,00	Very Feasible
Average	96,47	94,12	95,29	Very Feasible

Table 2 the expert validation results indicated that the critical thinking skills test instrument was highly feasible for use in this study. The overall feasibility percentage reached 95.29%, which falls within the "Very Feasible" category. The validators agreed that the instrument adequately represented the CTS indicators and met the requirements in terms of construction as well as language and sentence structure, although minor revisions were made based on their suggestions.

Following the instrument analysis, the effectiveness of Discovery Learning was initially examined through descriptive statistics of the pretest and posttest scores obtained by the experimental and control groups. The pretest was administered prior to the intervention to determine students' initial CTS, whereas the posttest was conducted after the learning intervention to evaluate changes in students' critical thinking performance. The descriptive statistics are presented in Table 3.

Table 3. Comparison of Pretest and Posttest Scores of Students' Critical Thinking Skills

Group	N	Pretest	Posttest
Experimental	31	55,10	82,55
Control	31	48,55	66,29

Based on Table 3, the average pretest score of the experimental class was 55.10, while the control class obtained an average score of 48.55. These findings indicate that the initial critical thinking skills of students in both classes were relatively low and not substantially different. This condition suggests that students had not yet fully developed the ability to analyze information, evaluate evidence, and formulate logical conclusions before the implementation of intervention.

Following the instructional intervention, both groups demonstrated improvements in their posttest scores. However, the increase observed in the experimental class was substantially greater

than that of the control class. The mean score of the experimental group increased from 55.10 to 82.55, whereas the control group's score increased from 48.55 to 66.29.

The normality test was performed to examine whether the distribution of the pretest and posttest scores met the assumption of normality required for parametric statistical analysis. The results of the normality test are presented in Table 4.

Table 4. Results of the Normality Test

Group	Test	Sig.	Decision
Experimental Pretest	Shapiro–Wilk	0,153	Normal
Experimental Posttest	Shapiro–Wilk	0,006	Not Normal
Control Pretest	Shapiro–Wilk	0,052	Normal
Control Posttest	Shapiro–Wilk	0,043	Not Normal

Based table 4, a normality test was conducted using the Shapiro–Wilk test because the sample size in each group was fewer than 50 participants. The results showed that the pretest scores of both the experimental and control groups were normally distributed (Sig. > 0.05). However, the posttest scores of both groups did not meet the assumption of normality (Sig. < 0.05). Therefore, a non-parametric statistical test, was employed to examine the differences between the two groups.

To determine the effectiveness of Discovery Learning in improving students' critical thinking skills, the improvement scores of both groups were analyzed using the normalized gain (N-Gain) test. Prior to hypothesis testing, the data were examined to ensure the appropriateness of the statistical procedure. Since the N-Gain data did not meet the assumption of normality, a non-parametric Mann–Whitney U test was employed to compare the improvement between the experimental and control groups (Quraisy & Madya, 2021). The results of the N-Gain analysis are presented in Table 5.

Table 5. Comparison of N-Gain Scores

Group	N	N-Gain	Category
Experimental	31	0,5647	Medium
Control	31	0,3213	Medium

(Afiesta et al., 2022)

Table 5 shows that the experimental group achieved a mean N-Gain score of 0.5647, while the control group obtained a mean score of 0.3213. According to the established classification criteria, both groups were categorized as having a moderate level of improvement. However, the experimental group demonstrated a substantially higher gain compared to the control group.

Although both groups experienced learning progress, the magnitude of improvement differed considerably. The higher N-Gain score obtained by the experimental class indicates that Discovery Learning was more effective in facilitating the development of students' critical thinking skills than the conventional learning approach implemented in the control class.

To further examine whether the observed differences in improvement were statistically significant, a Mann–Whitney U test was conducted. The results are presented in Table 6

Table 6. Mann–Whitney U Test

Statistic	Value
Mann-Whitney U	237.500
Wilcoxon W	733.500
Z	- 3.422
Asymp. Sig. (2-Tailed)	<0.001

Based on Table 6, the Asymp. Sig. (2-tailed) value is less than 0.05, so H_0 is rejected and H_1 is accepted. This result shows that there is a significant difference in the improvement of critical thinking skills between students who learn using Discovery Learning and conventional learning.

Table 7. Effect Size of Discovery Learning

Z Value	Total Sample (N)	Effect Size (R)	Category
-3,422	62	0,43	Medium

Based table 7, presents the effect size analysis of the Mann–Whitney U test. The analysis yielded an effect size value of r = 0.43, indicating a medium effect according to Cohen's criteria. This finding suggests that the implementation of Discovery Learning had a meaningful impact on improving students' critical thinking skills beyond mere statistical significance.

In addition to the test data measuring students' critical thinking skills, this study was also supported by students' response data collected through questionnaires administered to the experimental group after the completion of the learning activities. The questionnaire aimed to identify students' perceptions and experiences while participating in Discovery Learning on the topic of temperature and heat. The results of the questionnaire analysis are presented in Table 10.

Table 10. Students' Responses Toward the Learning Process

Students Number	Persentase (%)	Category
1	87.10	Very Good
2	82.58	Very Good
3	77.42	Good
4	79.35	Good
5	87.10	Very Good
6	82.58	Very Good
7	77.42	Good
8	79.35	Good
Average	**82.58**	**Very Good**

Based on Table 10, the average percentage of students' responses reached 82.58%, which falls into the very good category. This finding indicates that students generally had positive perceptions of the learning process implemented through the Discovery Learning model.

The highest percentage was observed in Item 8 (87.74%), followed by Item 1 (87.10%). These results suggest that most students perceived the learning activities as engaging and beneficial in supporting their understanding of the concepts being studied. On the other hand, the lowest percentage was found in Item 3 (77.42%), although it still fell within the good category. This result implies that some students may have encountered difficulties during certain stages of the discovery process, particularly when they were required to independently analyze information or formulate conclusions.

The relatively low pretest scores may be attributed to several factors. Physics learning in schools is often dominated by teacher-centered approaches, im which students tend to receive information passively rather than actively construct their own understanding. Consequently, students become accustomed to memorizing formulas and procedures without fully comprehending the underlying concepts or applying them to solve contextual problems. Similar findings were reported (Jamaludin et al., 2022), who found that students frequently experienced conceptual difficulties in understanding temperature and heat because they focused primarily on computational procedures rather than conceptual reasoning.

The greater improvement observed in the experimental group suggests that Discovery Learning provided more opportunities for students to actively engage in the learning process than conventional instruction. Through the stages of Discovery Learning, students were encouraged to identify problems, collect and analyze information, discuss alternative explanations, and justify conclusions based on evidence. Such activities are closely related to the development of critical thinking skills (Rahayu Gustika & Indra Sakti, 2018). The significance of this finding therefore extends beyond statistical interpretation, as active involvement in constructing knowledge contributes meaningfully to the enhancement of students' analytical and evaluative abilities. Similar observations were reported by (Kartikasari et al., 2018), who found that students participating actively in inquiry-oriented learning tended to demonstrate stronger critical thinking skills than those who learned through passive information reception.

The present findings are consistent with previous studies reporting the positive effects of Discovery Learning on students' critical thinking skills. Discovery Learning has been found to be effective in improving students' critical thinking skills in science learning through activities that encourage students to actively investigate problems and construct their own understanding (Syaras Fadillah & Erfan Ramadhani, 2021). Similarly, Discovery Learning has been shown to enhance students' critical thinking skills through inquiry-based learning experiences (Prasetyo & Mulyani, 2025). In addition, the implementation of Discovery Learning on temperature and heat topics has been reported to promote meaningful learning experiences and strengthen students' critical reasoning abilities (Baiq Ayu & Ahmad Didik, 2023). These findings collectively suggest that discovery-oriented instruction contributes to substantial improvements in students' higher-order thinking skills.

Despite these similarities, the present study offers a distinct contribution. Most previous studies investigated the effects of Discovery Learning on general science concepts or other physics topics, such as electricity and waves. In contrast, this study specifically examined the effectiveness of Discovery Learning in improving critical thinking skills on the topic of temperature and heat among senior high school students. Moreover, the effectiveness of the intervention was not only evaluated through N-Gain analysis but was also strengthened through non-parametric statistical testing and supported by student response data. Therefore, this study provides empirical evidence regarding the applicability of Discovery Learning within a specific local context and instructional topic (Syifa et al., 2023).

The findings of this study provide important implications for both theory and educational practice. From a theoretical perspective, the results reinforce Bruner's constructivist view, which posits that knowledge acquired through active discovery tends to be more meaningful and sustainable than knowledge obtained through passive reception. The improvement in students' critical thinking skills observed in the experimental group suggests that learning environments encouraging exploration, investigation, and evidence-based reasoning can facilitate the development of higher-order thinking skills (Larasati, 2020).

From a practical perspective, physics teachers may consider implementing Discovery Learning supported by LKPD to promote active participation, collaborative problem-solving, and critical reflection, particularly when teaching temperature and heat concepts (Suarti, 2022).

The practical significance of these findings was further supported by the effect size analysis, which yielded an r value of 0.43, indicating a moderate effect according to Cohen's criteria (Cohen, 2013). This result demonstrates that Discovery Learning not only produced statistically significant differences but also exerted a meaningful educational influence on students' critical thinking skills. The opportunities provided through active exploration, collaborative discussion, and evidence-based

reasoning appeared to facilitate students' ability to interpret information, analyze problems, evaluate evidence, draw conclusions, and formulate explanations.

This study has several limitations. First, the investigation focused exclusively on the topic of temperature and heat. Although the findings indicate the effectiveness of Discovery Learning within this context, caution should be exercised when generalizing the conclusions to other physics topics that may involve different conceptual structures and learning demands (Trihartini et al., 2025). In addition, the participants were drawn from a single school with a relatively limited sample size, which may restrict the broader generalizability of the findings.

These limitations open opportunities for future research. Subsequent studies are recommended to involve larger and more diverse samples from different schools and educational settings. Future researchers may also employ mixed-methods approaches to gain a more comprehensive understanding of how Discovery Learning influences students' critical thinking processes. Moreover, investigating the effectiveness of Discovery Learning across other physics topics, such as electricity, waves, fluids, or modern physics, may provide broader evidence regarding the applicability of the model.

Overall, the findings of this study demonstrate that Discovery Learning is not merely an instructional model aimed at improving academic achievement. More importantly, it serves as a learning approach capable of fostering students' critical thinking skills, encouraging active participation, and promoting meaningful learning experiences. The findings suggest that Discovery Learning can be considered an effective instructional alternative in physics education, particularly for facilitating the development of competencies required in the twenty-first century.

CONCLUSION

This study confirms that the Discovery Learning model is effective in improving senior high school students' critical thinking skills in learning temperature and heat concepts. Students who participated in Discovery Learning demonstrated better improvement in critical thinking skills than those who received conventional instruction. These findings indicate that learning experiences emphasizing exploration, problem identification, data analysis, verification, and conclusion drawing can facilitate the development of higher-order thinking skills and encourage students to become active participants in constructing knowledge.

The findings highlight the importance of implementing student-centered instructional approaches in physics education. Discovery Learning not only supports students' conceptual understanding but also promotes meaningful learning experiences that foster critical thinking, collaboration, and active engagement during the learning process. The novelty of this study lies in its examination of the effectiveness of Discovery Learning specifically on the topic of temperature and heat through the integration of N-Gain analysis, Mann–Whitney U testing, and student response data, thereby providing empirical evidence within the context of senior high school physics learning.

These results may serve as a practical reference for physics teachers in designing learning activities that emphasize inquiry and critical reasoning. This study has several limitations. First, the participants were drawn from a single school with a relatively limited sample size, which may restrict the generalizability of the findings. Second, the investigation was confined to the topic of temperature and heat, so the effectiveness of Discovery Learning on other physics topics remains uncertain. Future studies are recommended to involve participants from different schools and educational settings to enhance the generalizability of the findings. Further research may also explore the implementation of Discovery Learning on other physics topics and employ mixed-methods approaches to gain deeper insights into how students' critical thinking skills develop throughout the learning process.

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