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The Effect of Inquiry-Based Learning on Students' Critical Thinking Skills in Science Learning (Junior High School-Senior High School): Meta-Analysis

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Abstract: Critical thinking skills are crucial 21st-century skills. However, students' critical thinking skills are still considered low in several studies. Science learning is closely related to this ability. One learning model believed to effectively improve critical thinking skills is the inquiry-based learning model. This study is a meta-analysis study that aims to examine and determine the effect of the inquiry learning model on improving secondary school students' critical thinking skills in science learning as a whole. Article searches were conducted using PoP on Google Scholar and obtained 11 final articles for analysis. The analysis process used Comprehensive Meta-Analysis (CMA) with the Hedges formula. The results of this study indicate that the fixed-effects model has an effect size of 1.07 (std. error 0.08), while the random-effects model has an effect size of 1.16 (std. error 0.37). This means that inquiry learning has a significant effect on improving critical thinking skills despite study variations. These results are not easily influenced by the possibility of publication bias.

Keywords: Critical Thinking Skills; Inquiry Learning; Meta-Analysis; Science Learning

Introduction

Science learning provides students with the opportunity to think critically and solve problems in real life (Hugerat et al., 2021; Suendarti & Virgana, 2022). Critical thinking skills are core skills in 21st century education which are very important in facing global challenges (Patras et al., 2024; Rahim, 2023; Rendi et al., 2024; Yulianti et al., 2022). 21st-century learning refers to the 4Cs, namely the skills possessed, such as problem-solving, critical thinking, collaboration, and communication skills (Taufiqurrahman, 2023).

Science is closely related to this ability. Critical thinking helps students make rational, reflective, and reasoned decisions (Fajari et al., 2020; Lestari et al., 2020). In addition, critical thinking as the basis of students' scientific literacy faces global and technological challenges through analyzing information, evaluating arguments, solving complex problems, and making the right decisions (Azmi et al., 2025; Fitriyah et al., 2021; Ramdani et al., 2021).

However, the main problem encountered in science learning is the failure to achieve appropriate critical thinking competencies. Several studies have shown that Indonesian students' critical thinking skills are still low and need to be improved (Dewi et al., 2023; Haris et al., 2024; Hatria et al., 2022; Lidiawati et al., 2022; Selvi et al., 2025; Sugiharti & Gayatri, 2024). This low ability is due to science learning tending to be teacher-centered, minimal student involvement, and a lack of learning innovation so that material concepts are difficult to understand (Annisa et al., 2022; Puspita et al., 2023; Rahman et al., 2023).

Based on analysis conducted by PISA 2022, Indonesian students' critical thinking skills are also still considered low. PISA 2022 results show that Indonesia's

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creative thinking score is only 19 out of 60, far below the OECD average of 33. Only 31% achieved level 3, compared to 78% of OECD students. Indonesia also remains lowly ranked, ranking 70th (mathematics), 71st (reading literacy), and 67th (science) out of 81 countries (OECD, 2024).

Efforts to improve critical thinking skills in schools often face obstacles, both on the part of teachers and schools. In this regard, it is crucial that the learning process and environment be directed or focused on these skills (Fajriati et al., 2024). Inquiry-based learning can be a solution to address these issues. Inquiry-based learning provides students with the opportunity to actively participate, seek information, discuss, and analyze problems in depth and systematically, thereby fostering critical thinking (Ningsih, 2025; Sonia et al., 2023; Sutiani et al., 2021). This is in accordance with constructivism theory that understanding is formed through a process of investigation and direct involvement (Suryana et al., 2022).

Inquiry-based learning can have a significant influence and improve students' critical thinking skills (Martatis, 2023; Bakri et al., 2021; Utami, 2022). In addition, inquiry in science learning also encourages students to reason deductively, so that there is an increase in understanding and skills in the science process (Suherta et al., 2023). This learning produces a more effective learning process than conventional learning because it is more student-centered and meaningful (Suwardani et al., 2021).

Several experimental studies have shown that inquiry-based learning does not always produce significant improvements in these skills compared to conventional learning. These inconsistent findings create uncertainty in instructional decision-making, particularly in science learning at the junior and senior high school levels. These discrepancies indicate a research gap that needs to be addressed through a more systematic approach. Therefore, a meta-analysis of several studies is needed to integrate the various results and obtain a more concrete picture.

In addition, similar meta-analysis studies have been conducted, including Arifin et al. (2025) who studied the influence of the inquiry learning model on critical thinking skills in science education. Other researchers, namely Syahgiah et al. (2023) examine the influence of science learning on process skills and critical thinking. Susanto & Indarini (2022) This study also examined the effects of inquiry-based learning on the critical thinking skills of elementary school students in thematic areas. However, it did not focus on secondary education, which is a crucial stage in the development of critical thinking skills. The urgency of this research lies in providing empirical evidence to determine effective science learning strategies in accordance with curriculum requirements.

Based on this background, a more systematic study is needed to provide a holistic view. This meta-analysis will examine various primary studies in several published studies, hopefully providing a comprehensive picture of the extent to which inquiry-based learning can improve critical thinking skills.

Method

This study used a meta-analysis approach, a systematic method used to integrate and analyze findings from various studies related to the implementation of inquiry-based learning in science education and efforts to improve critical thinking skills in secondary school students.

Meta-analysis is a research methodology that evaluates and synthesizes findings from various previous studies containing quantitative data that can be analyzed statistically (Chen et al., 2022). Through this study, the effect of inquiry-based learning on critical thinking skills as a whole will be examined. The systematic steps in conducting a meta-analysis are as follows.

Formulating Questions

Formulating research questions:

RQ1. Does inquiry-based learning have a significant impact on critical thinking skills?

RQ2. What is the overall effect size of inquiry-based learning on critical thinking skills?

Study Selection Criteria

The researchers determined inclusion criteria, including publications from 2016-2025; experimental (quasi-experimental) articles; articles containing mean data, sample size, and SD; full-text and open access articles; and articles in Indonesian or English.

Data Collection

The article selection process was conducted using the PRISMA 2020 method, which ensures transparency and accountability in the literature search process. A search was conducted on Google Scholar using the keywords "the influence of inquiry learning on critical thinking," "inquiry models," and "science learning." The selection process based on the PRISMA stages is presented in Figure 1.

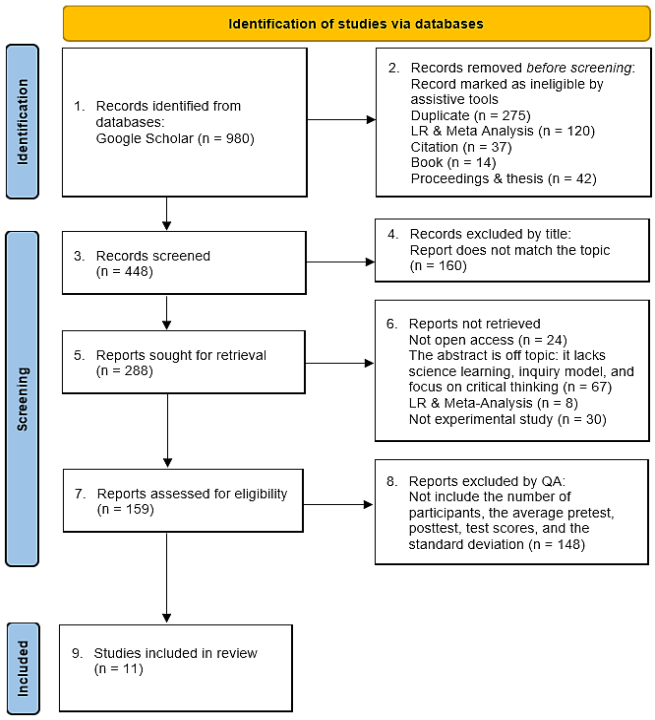

Figure 1. Article Search Results

Data encoding

Pengkodean data dalam meta-analysis bertujuan to facilitate data analysis (Chamdani et al., 2022). The coding process was carried out by sorting and compiling complete descriptions related to article codes and information including the sample size (N), mean, and SD for the experimental and control groups. This data will be used as primary data for further analysis.

Data Analysis

In meta-analysis, the data analysis process involves determining effect size values based on primary study data, testing for publication bias, developing estimation models, checking for publication bias, and calculating p-values to prove hypotheses (Joseph, 2023). The data analysis process was conducted using the Comprehensive Meta-Analysis (CMA) tool. This analysis included quantitative and descriptive data. The criteria for determining effect size were based on Cohen's (1998) criteria, which can be seen in Table 1.

Table 1. Effect Size Level Categories (Cohen, 1998)

Effect Size (ES)	Interpretation
0.00 ≤ ES < 0.20	Ignoret
0.20 ≤ ES < 0.50	Small
0.50 ≤ ES < 0.80	Moderate
0.80 ≤ ES < 1.30	Large
1.30 ≤ ES	Very Large

Results and Discussion

Based on the overall selection results, 11 articles met the established inclusion criteria. These articles were further analyzed in a meta-analysis as the primary data source for this research title. The selection results indicated that the majority were quasi-experimental studies. The analysis of these 11 articles is shown in Table 2.

Table 2. Results of the Selected Articles

Code	Author/Year	Method
A01	(Ernawati et al., 2025)	Quasi Experiment
A02	(Ritli & Adlini, 2022)	Quasi Experiment
A03	(Maryam et al., 2020)	Quasi Experiment
A04	(Carolina et al., 2020)	Experiment
A05	(Carolina et al., 2020)	Quasi Experiment
A06	(Santoso & Arif, 2021)	Experiment
A07	(Suhidi et al., 2021)	Quasi Experiment
A08	(Nerli et al., 2023)	Quasi Experiment
A09	(Danisa et al., 2016)	Quasi Experiment
A10	(Irma et al., 2023)	Quasi Experiment
A11	(Zai et al., 2023)	Quasi Experiment

Based on the article, a quantitative data extraction process was conducted, including the sample size (N), mean, and standard deviation (SD) of the experimental and control groups in the article. This data will be used as the basis for determining the effect size of several studies. The results of the data extraction are shown in Table 3.

Table 3. Primary Data Results for Both Groups

Code	Data Search Results					
	Experiment			Control		
	N	Mean	SD	N	Mean	SD
A01	22	75.79	7,21	21	64.98	10.28
A02	26	26	10.147	26	60.58	7.393
A03	40	81.785	6.569	38	68.519	13.449
A04	32	79.68	9.840	32	66.48	9.070
A05	77	69.2	13,0	77	60.4	11.9
A06	28	80.18	8.02	30	52.58	7.41
A07	76	69.58	9.13	76	63.4	8.09
A08	27	80.37	8.195	27	70.19	7.136
A09	36	80,37	9.554	34	63,09	11.104
A10	35	80,83	1.16190	36	76.71	1.02321
A11	25	80,07	3.31	25	75.20	2.77

In this study, the effect size data from the N, Mean, and SD were analyzed using the Comprehensive Meta-Analysis (CMA) tool. Based on this analysis, data related to effect size, standard error, and confidence intervals were obtained, thus determining the magnitude of the study's effect size. These results are shown in Table 4.

Table 4. Analysis Results (Effect Sizes, Standard Errors, and Confidence Intervals)

Code	Effect Size	Standard Error	Confidence Intervals	
			Lower Limit	Upper Limit
A01	0.65	0.31	0.04	1.25
A02	-3.84	0.46	-4.75	-2.93
A03	1.25	0.25	0.77	1.73
A04	1.38	0.28	0.84	1.92
A05	0.70	0.17	0.38	1.03
A06	3.53	0.42	2.71	4.35
A07	0.71	0.17	0.39	1.04
A 08	1.31	0.30	0.73	1.89
A09	1.65	0.27	1.12	2.19
A10	3.73	0.39	2.96	4.49
A11	1.57	0.32	0.94	2.20

Based on Table 4, the highest effect size values were found in six studies, namely A04 (1.38), A06 (3.53), A08 (1.31), A09 (1.65), A10 (3.73), and A11 (1.57). One study, A02 (-3.84), showed a negative effect size. Furthermore, the standard error ranged from 0.17 to 0.46, indicating good precision for the estimated effect size. The results also indicated that the confidence interval was significant. The distribution of the study's effect size levels based on the established levels (Cohen 1998) can be seen in Figure 2.

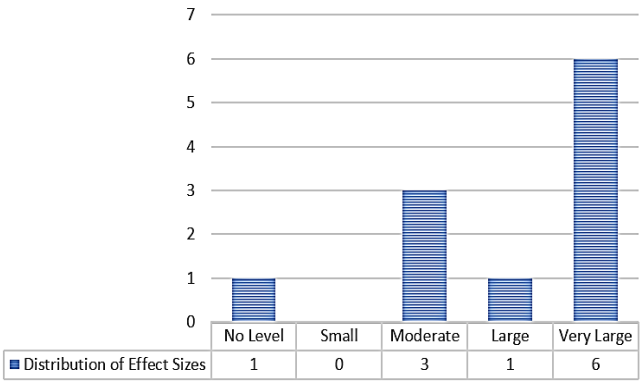

Figure 2. Distribution Effect Size

Figure 2 shows that the effect sizes are mostly in the medium to very high category, indicating that inquiry-based learning has a positive influence on critical thinking skills. In this study, publication bias was assessed using a funnel plot to determine whether there is a tendency for significant study results to be published more often than non-significant ones.

The funnel plot visualizes the distribution of effect sizes (Hedges's g) against the standard error of each study. The funnel plot shows that the distribution of studies is not completely symmetrical around the combined effect. Several studies fall outside the funnel area, particularly on the left and right sides, which could indicate potential publication bias or heterogeneity between studies. Publication bias based on the analysis is shown in Figure 3.

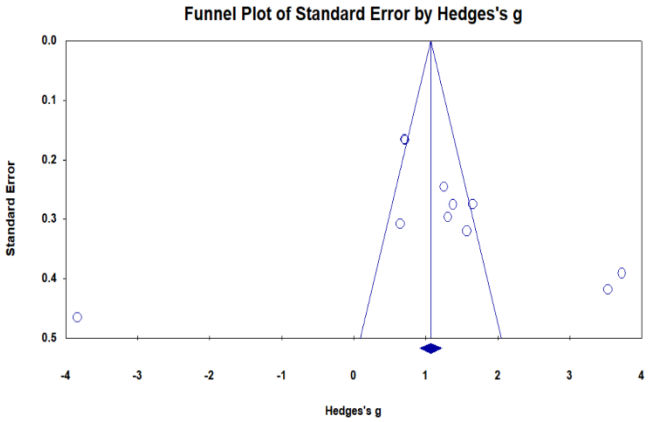

Figure 3. Publication Bias (Funnel Plot)

Figure 3 shows that the funnel plot indicates publication bias between studies. The distribution of points on the funnel shows that there are studies far to the left and far to the right, which may be influenced by external factors, such as differences in study subjects or sample size. Therefore, further statistical testing using Egger's Test is important to confirm whether publication bias is indeed present. The results of Egger's Test are presented in Table 5.

Table 5. Egger's Test Results

Statistics	Value
Intercept	2.31975
Std error	4.49312
95% lower limit (2-tailed)	-7.84440
95% upper limit (2-tailed)	12.48390
t-value	0.51629
df	9.00000
P-value (1-tailed)	0.30905
P-value (2-tailed)	0.61810

Based on Table 5, the results show an intercept value of 2.31975 with a p-value > 0.05 (0.618 > 0.05), indicating no indication of publication bias, as indicated by the less asymmetric funnel plot. Furthermore, these results are supported by the fail-safe N value in Table 6.

Table 6. Results of Fail-safe N Analysis

Statistics	Value
Z-value	13.80764
P-value	0.00000
Alpha	0.05000
Tails	2.00000
Z for alpha	1.95996
Number of observed stuides	11.00000
Number of missing studies that would bring p-value to > alpha	535.00000

The fail-safe N value indicates that at least 535 additional studies that did not show a significant effect are needed for the meta-analysis to lose significance ($p > 0.05$). This number is significantly larger than the 11 studies analyzed, making the findings of this meta-analysis robust and resistant to possible publication bias. Furthermore, to answer the research hypothesis, we analyzed the effect size and 95% confidence interval (CI) for both the fixed and random models.

Table 7. Effect Size and 95% Confidence Interval

Model	Effect Size and 95% Confidence Interval				
	N	Z-value	P-value	Effect Size	Std. Error
Fixed	11	13.74	0.00	1.07	0.08
Random	11	3.11	0.00	1.16	0.37

The results of a meta-analysis of 11 studies indicate that the inquiry learning model studied significantly impacted critical thinking skills. Based on the fixed effects model, the effect size was 1.07 with a standard error of 0.08, and a Z-value of 13.74 ($p < 0.001$). This value indicates a statistically significant effect on improving critical thinking, assuming that all studies had a uniform effect.

However, because the data showed significant variation between studies, a random effects model was used as the primary basis for interpretation. In this model, the effect size was 1.16 with a standard error of 0.37 and a Z-value of 3.11 ($p < 0.001$), also indicating a significant effect. Based on Cohen's (1988) interpretation, an effect size value above 0.80 is categorized as a large effect, indicating that the learning model studied generally had a significant effect on improving critical thinking skills. This effect would be considered educationally meaningful, not merely statistically significant.

Table 8. Results of Prediction Intervals and Heterogeneity

Prediction Interval		Other Heterogeneity Statistics			
Lower	Upper	Q-value	df (Q)	P-value	I-squared
		213.03	10.00	0.00	95.31
-1.67	4.00				

Analysis of the heterogeneity level revealed a Q value of 213.03 with 10 degrees of freedom (df) and $p < 0.001$, indicating significant differences between studies. An I^2 value of 95.31% indicates that approximately 95% of the variation in effect size between studies is due to significant differences in study characteristics (such as design, context, population, or learning model implementation), rather than sampling error. This very high heterogeneity reinforces the rationale for using a random effects model (Selvi et al., 2025).

The random effects model also yielded a prediction interval ranging from -1.67 to 4.00. This interval provides an indication of the potential variation in effect size if the study were repeated under different conditions. The wide range, including negative values, indicates that in some contexts, the learning model may produce small or even negative effects. This confirms that the effectiveness of learning models is not universal, but rather depends on the implementation context and student characteristics. Furthermore, considering the fail-safe N value, which demonstrates the stability of meta-analysis results against potential publication bias, the findings are robust and reliable.

Conclusion

The results of this meta-analysis indicate that inquiry-based learning has a significant impact on improving critical thinking skills. The effect size for both the fixed-effects model was 1.07 (std. error 0.08) and the random-effects model was 1.16 (std. error 0.37). This suggests that inquiry-based learning significantly impacts critical thinking skills and is recommended for science learning. This research is limited to secondary education and the number of studies reviewed, requiring careful generalization. Future research is recommended to expand the sample size and further examine moderating variables such as the type of inquiry or science topic.

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S.N.P.D. article search, analysis, writing, submission; I.W.R. article review; I.N.T. article review.

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Conflict of Interest
The authors declare no internal or external conflicts of interest.

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