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The Effect of Socio-Scientific Issue-Based Learning on Students' Argumentation Skills in Science Education: A Meta-Analysis

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Abstract: Scientific argumentation is a crucial 21st-century skill in science education, yet many Indonesian students still struggle to construct evidence-based arguments. This study conducted a meta-analysis to evaluate the effect of Socio-Scientific Issue (SSI)-based learning on students' argumentation skills. Twelve primary studies that met the inclusion criteria were analyzed using Comprehensive Meta-Analysis (CMA) software, with effect sizes calculated using Hedges's g. The analysis revealed very high heterogeneity among the studies (I^2 = 96.56%), indicating substantial variation in results. Under the random-effects model, which is more appropriate in this condition, the pooled effect size was negative and not statistically significant (ES = -0.588, p = 0.16). Although the fixed-effect model produced a significant positive effect (ES = 0.329, p = 0.000), this result is less reliable because it does not account for the high variability across studies. Publication bias tests suggested potential bias but did not alter the overall interpretation. These findings indicate that the effectiveness of SSI-based learning on argumentation skills is inconsistent across contexts. Therefore, while SSI-based learning shows potential in specific settings, its overall impact remains uncertain and requires cautious interpretation.

Keywords: Argumentation Skills; Learning Approach; Meta-Analysis; Science Education; Socio-Scientific Issues.

Introduction

Argumentation skills are one of the essential competencies in 21st-century science education. Current science learning emphasizes communication as a fundamental skill, and one important form of communication is scientific argumentation, which involves claims, data, reasoning, and rebuttals (Wahyuni et al., 2024). In the context of science education, argumentation not only reflects students' conceptual understanding but also fosters critical thinking, decision-making, and scientific communication skills necessary for addressing real-world issues (Beniermann et al., 2021; Bima & Fauziah, 2023; Telenius et al., 2020).

Despite its importance, studies have shown that Indonesian students' argumentation skills remain relatively low, both in terms of structure and quality of reasoning. Many students are only able to state claims without logical reasoning or strong scientific evidence. For example, Amalina et al. (2020) found that most junior high school students are only at the initial level of scientific argumentation, lacking adequate elaboration of evidence. Minin & Fauziah (2022) reported that high school students are not yet accustomed to constructing arguments systematically and often struggle to provide data-based justifications. Similarly, Agusni et al. (2023) highlighted that students had difficulty formulating arguments based on scientific evidence within socio-scientific contexts. These findings suggest that current science instruction requires more contextualized approaches to effectively strengthen students' argumentation skills.

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One promising approach is Socio-Scientific Issues (SSI)-based learning, which connects science content with real-world social issues such as climate change, biotechnology, pollution, and renewable energy (Siska et al., 2020). Through SSI, students are encouraged to construct arguments, evaluate evidence, and consider multiple perspectives (Astarina et al., 2019; Nurtamara & Widyastuti, 2023). Several studies have demonstrated its benefits. Research by Wati et al. (2023) showed that SSI-based e-modules improved student engagement in interactive learning activities such as discussions and debates. Likewise, Purwati et al. (2019) reported that problem-based learning modules integrating SSI were more effective in enhancing argumentation skills compared to conventional modules. These findings indicate that SSI provides meaningful learning contexts that can improve students' reasoning and argumentation abilities.

However, the effectiveness of SSI-based learning remains inconsistent. Some studies report significant positive impacts, while others find limited or non-significant effects. These variations may be influenced by differences in research design, participants, instructional models, or the indicators used to measure argumentation. Such inconsistencies make it difficult to draw firm conclusions about the overall effectiveness of SSI.

Based on this gap, a systematic and quantitative synthesis is needed to obtain a clearer picture of the impact of SSI-based learning on students' argumentation skills. Therefore, this study employs a meta-analysis to calculate and analyze the effect sizes reported in previous studies. The novelty of this research lies in its focus on synthesizing empirical findings specifically on argumentation skills within SSI-based learning in science education, which has not been comprehensively addressed in prior meta-analyses. The results are expected to provide more robust evidence for educators and researchers on the potential and limitations of SSI as an instructional approach to foster argumentation skills.

Method

This study employed a meta-analysis research design, a quantitative technique used to integrate the results of multiple primary studies for analysis and synthesis (Batdi et al., 2019). The stages of conducting the meta-analysis, as outlined (Retnawati et al., 2018) are presented in Figure 1.

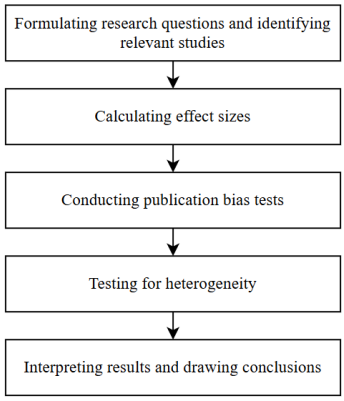

Figure 1. Meta-analysis steps

Formulating the research question and identifying relevant studies

The initial stage begins with formulating the research question. Subsequently, the researcher establishes inclusion criteria to select literature pertinent to the focus of the study. In the process of searching for research articles, Harzing's Publish or Perish software was used with the following criteria: publication 2019-2025; the article is a primary study; the article employs an experimental or quasi-experimental research method; the article contains statistical data (mean scores, sample size, standard deviation, and p-value); and the article is full-text and open-access.

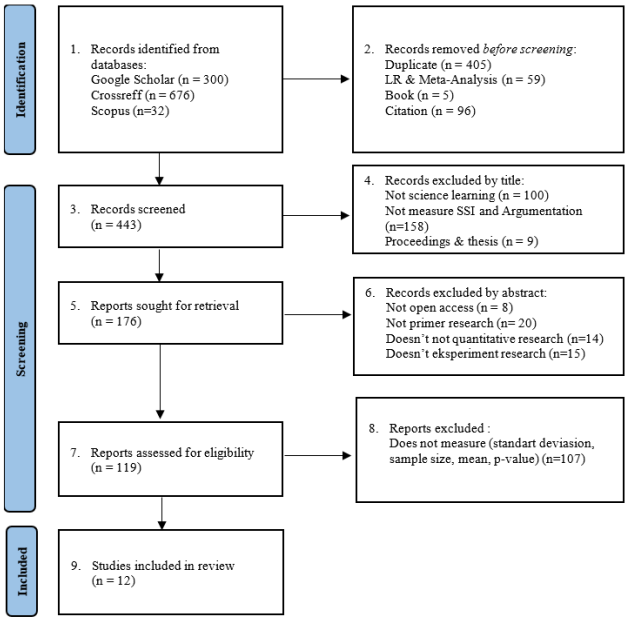

Figure 2. Prisma Method

Calculating the effect size

Quantitative data from the selected primary studies were integrated and statistically analyzed to calculate the effect size. This process was carried out using the *Comprehensive Meta-Analysis (CMA)* software. The effect

size values were interpreted using the classification developed by Cohen (1988) as presented in Table 1.

Table 1. Cohen's effect size classification

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

Conducting publication bias tests

To identify potential publication bias, three types of tests were conducted: (1) the funnel plot test to assess the distribution of effect sizes visually, (2) the fail-safe N test to determine the robustness of the results against unpublished studies, and (3) the trim and fill test to estimate and adjust for missing studies statistically.

Heterogenity test

This test aims to assess the extent of variability among the analyzed studies. The heterogeneity test results serve as the basis for determining the appropriate estimation model, either the fixed-effect model or the random-effect model.

Interpretation of results and drawing conclusions

The final stage of the meta-analysis involves interpreting the findings and drawing conclusions based on the effect size values and the results of other statistical tests.

Result and Discussion

After the overall process of searching and selecting primary studies, 12 articles were identified as meeting the inclusion criteria and were deemed suitable for further analysis in this meta-analysis. Table 2 presents a summary of information from these twelve studies, which served as the basis for the analysis in this research.

Table 2. Summary of Included Research Articles

Code	Author/Year	Method
Study 01	(Yuberti et al., 2019)	Quasi-experimental
Study 02	(Martini et al., 2021)	Experimental
Study 03	(Nugroho et al., 2024)	Quasi-experimental
Study 04	(Wahidah et al., 2024)	Quasi-experimental
Study 05	(Pertiwi et al., 2023)	Quasi-experimental
Study 06	(Yuliyani et al., 2021)	Quasi-experimental
Study 07	(Fadha et al., 2023)	Quasi-experimental
Study 08	(Atabey & Topcu, 2017)	Experimental
Study 09	(Nurtamara & Widyastuti, 2023)	Experimental
Study 10	(Atabey & Topcu, 2017)	Quasi-experimental
Study 11	(Dawson, 2024)	Experimental
Study 12	(Setyaningsih et al., 2019)	Experimental

Subsequently, all selected studies were subjected to data extraction based on the required statistical information and study characteristics. The results of the data extraction are presented in Table 3.

Table 3. Recapitulation of Data Extraction Results

Code	Statistical Data						P-value
	Experimental Group			Control Group			
	Mean	SD	N	Mean	SD	N	
Study 01	81.56	9.93	34	71,08	10,02	36	
Study 02	52.22	6.62	32	85.78	4.72	32	
Study 03	78,38	6.59	44	70.05	7.63	46	
Study 04	76.93	10.85	28	34.43	15.26	28	
Study 05	78.85	11.27	26	54.15	10.96	26	
Study 06	86.55	20.98	29	80.00	6.617	29	
Study 07	38.79	9.80	66	35.45	14.63	66	
Study 08			21			21	0.001
Study 09			35			36	0.001
Study 10			24			24	0.002
Study 11			48			48	0.033
Study 12			36			36	0.001

Table 3 presents data extracted from primary studies, categorized into two groups based on the type of statistical data provided: (1) studies that reported the mean (M), standard deviation (SD), and sample size (N), which include Study 01 through Study 07; and (2) studies that reported sample size and p-values, namely Study 08 through Study 12.

The primary analysis in this study aims to determine the magnitude of the effect of the Socio-Scientific Issue (SSI)-based learning approach on students' argumentation skills in science education. Effect size calculations were done using the Comprehensive Meta-Analysis (CMA) software.

A detailed overview of the effect sizes from each primary study is presented in Table 4, including the effect size values, the lower and upper bounds of the confidence intervals, and the standard error for each analyzed study.

Table 4. Study effect sizes, confidence intervals, and standard errors

Code	Effect Size	Confidence Intervals		Standard Error
		Lower Limit	Upper Limit	
Study 01	1.039	0.544	1.533	0.252
Study 02	-5.767	-6.877	-4.657	0.566
Study 03	-9.617	-11.081	-8.154	0.747
Study 04	0.316	-0.203	0.836	0.265
Study 05	0.312	-0.227	0.851	0.275
Study 06	0.042	-0.466	0.549	0.259
Study 07	0.267	-0.074	0.607	0.174
Study 08	1.075	0.439	1.712	0.325
Study 09	0.807	0.328	1.286	0.244
Study 10	0.931	0.344	1.517	0.299
Study 11	0.438	0.037	0.840	0.205
Study 12	0.801	0.326	1.276	0.243

Table 4 shows that the effect size values of the analyzed studies range from -9.617 to 1.075, within a 95% confidence interval. The highest effect size was found in Study 08 (1.075), while the lowest was observed in Study 03 (-9.617). The majority of the studies reported positive effect sizes.

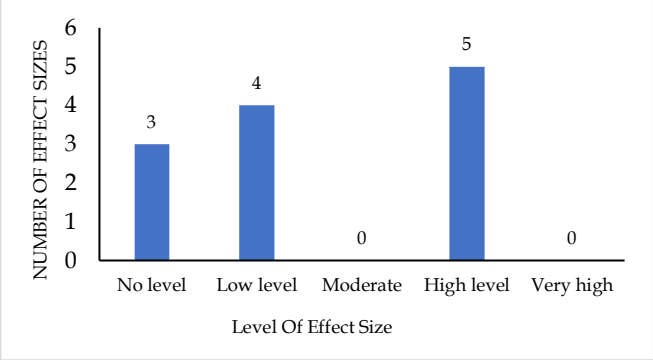

Figure 3. Classification of effect sizes

Meanwhile, Figure 3 presents the effect size levels of all studies based on Cohen (1988) classification. Figure 3 shows that the effect size levels of the analyzed studies vary across several categories. Three studies fall into the no-effect category, indicating no meaningful impact on students' argumentation skills. Four studies are categorized as low-level, indicating a small effect.

Meanwhile, no studies were found in the moderate or very high effect size categories. The most dominant category was high level, with five studies indicating that Socio-Scientific Issue (SSI)-based learning has a strong impact on improving argumentation skills.

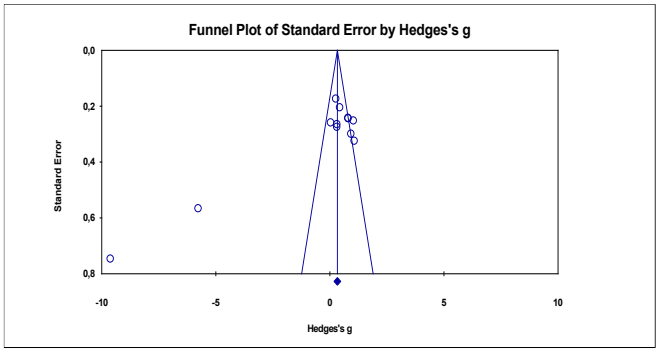

Figure 4. Funnel Plot Publication Bias Test

Subsequently, a publication bias analysis was conducted to ensure the reliability of the data. The analysis included a funnel plot and a fail-safe N (FSN) test. Figure 3 illustrates the distribution of effect sizes from each study using a funnel plot.

A funnel plot was used to evaluate the potential presence of publication bias in the analyzed studies, mapping the standard error against the effect size (Hedges's g) of each study. As shown in Figure 4, the funnel plot displays the distribution of effect sizes from the primary studies included in the analysis. Visually, most data points are concentrated around the vertical line representing the overall mean effect size, forming a funnel-shaped pattern.

However, the distribution of the data points is not perfectly symmetrical. Two extreme data points are located far outside the funnel boundaries on the lower left side of the plot, indicating highly negative Hedges's g values accompanied by high standard errors. These points can be considered potential outliers and may indicate an imbalance in the data distribution.

To confirm the results of the funnel plot analysis, an additional publication bias test—fail-safe N—was conducted. The results generated from the Comprehensive Meta-Analysis (CMA) software are presented in Table 5.

Table 5. Results of the Fail-Safe N Test

Classic Fail-Safe N	
Z-value for observed studies	0.06985
P-value for observed studies	0.94431
Alpha	0.00001
Tails	2.00000
Z for alpha	4.41717
Number of observed studies	12
Number of missing studies that would bring p-value to > alpha	0

Based on Table 5, the p-value from the Z statistic for the observed primary studies is 0.94431, which means p > 0.05. This indicates that the effect sizes obtained from the primary studies are not statistically significant. Furthermore, with a total of 12 studies analyzed, the fail-safe N value is 0, suggesting that the results of this meta-analysis are vulnerable to publication bias and are not yet robust enough to serve as a solid basis for conclusions.

This means that the effect size results from the analyzed studies are not sufficiently resistant to publication bias and, therefore, require further analysis, such as a trim and fill test or sensitivity analysis, to ensure the consistency of the findings. The results of the trim and fill test are presented in Table 6.

Table 6 presents the results of Duval and Tweedie's trim and fill test to detect potential publication bias. Based on the observed values, two studies were imputed, decreasing the effect size from 0.329 to 0.207, with a confidence interval ranging from 0.068 to 0.346. Under the random-effects model, the effect size change was insignificant, shifting from -0.588 to -0.583, with a confidence interval of -1.394 to 0.143. The Q-value also slightly increased to 340.41 after adjustment. These findings suggest the presence of potential publication bias, particularly under the fixed-effect model. The final stage involves calculating the p-value to test the research hypothesis. Table 4 compares the analysis results based on the estimation models.

The comparison of fixed-effect and random-effects estimation models is presented in Table 7. Based on the fixed-effect model, the effect size was 0.329 with a standard error of 0.076, and the 95% confidence interval ranged from 0.180 to 0.477. A Z-value of 4.342 and a p-value of 0.000 indicate that the Socio-Scientific Issue (SSI)-based learning approach has a statistically significant positive effect on students' argumentation skills.

Table 6. The results of the trim and fill test

Model	Studies Trimmed	Point	Confidence Interval (95%)		Q Value
			Lower Limit	Upper Limit	
Observed values	2	0.207	0.068	0.346	340.41
Adjusted values	2	-0.583	-1.309	0.143	340.41

However, under the random-effects model, the effect size shifted to -0.588 with a standard error of 0.419. The 95% confidence interval became wider, ranging from -1.410 to 0.233. A Z-value of -1.404 and a p-value of 0.160 indicate that the effect is not statistically significant in this model.

Table 7. Comparison of Results Based on Estimation Models

Estimation Model	n	Z-value	p-value	Effect Size	Standard Error	95% CI		*Qb*	p-value	I^2 (%)
						Lower	Upper			
Fixed Effect	12	4.342	0.000	0.329	0.076	0.180	0.477	319.759	0.000	96.560
Random Effect	12	-1.404	0.160	-0.588	0.419	-1.410	0.233			

The heterogeneity test revealed a very high level of variability among the studies, as indicated by an I^2 value of 96.56%, meaning that approximately 96% of the variation in effects is due to differences between studies. This is further supported by a Q-value of 319.759 ($p < 0.001$), indicating significant heterogeneity.

Based on the data presented above, the meta-analysis on the implementation of Socio-Scientific Issue (SSI)-based learning about students' argumentation skills yielded an effect size of 0.329 (fixed-effect model), which falls within the moderate-to-high category. This result suggests that the SSI approach has the potential to influence the development of students' scientific argumentation skills positively. Although the random-effects model produced a negative, non-significant effect size (-0.588; $p = 0.160$), this outcome is likely influenced by the very high level of heterogeneity among the studies ($I^2 = 96.56\%$; $Q = 319.759$; $p < 0.001$), as well as the presence of two extreme studies that may have suppressed the overall combined effect.

These findings are consistent with the meta-analysis conducted by Pyatt (2014), which reported a large effect size (1.08) for SSI in the context of scientific literacy, including aspects of reasoning and argumentation, even when using a random-effects model. Similarly, (Dawson, 2024) found that the SSI approach, when applied in the context of water-related issue discussions, led to an improvement in argumentation quality from an average score of 2.09 to 2.41 with a moderate effect size (d = 0.49 to 0.58).

Therefore, it can be concluded that Socio-Scientific Issue (SSI)- based learning holds strong potential to enhance students' argumentation skills. Although variations in results were observed across studies, the evidence from this meta-analysis supported by findings from previous research indicates that the SSI approach is effective in fostering evidence-based argumentation skills in science education.

Conclusion

This meta-analysis study concludes that the implementation of Socio-Scientific Issue (SSI)-based learning has the potential to influence students' argumentation skills in science education positively. The fixed-effect model showed a moderate to high effect size (ES = 0.329), indicating a statistically significant impact. However, the random-effect model produced a non-significant result (ES = -0.588), likely due to high heterogeneity among studies (I^2 = 96.56%). Despite this variation, previous research and supporting evidence confirm the effectiveness of SSI in enhancing students' scientific reasoning and evidence-based argumentation. Thus, SSI-based learning can be considered a practical and contextually relevant instructional approach to improve students' argumentation skills in science.

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Author Contributions
L.P.S.D searched for articles, analyzed the data, wrote the manuscript and submitted; I W. R. reviewed the manuscript; I.N.T reviewed the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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