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The Relationship between Critical Thinking and Learning Outcomes in Science and Mathematics Subjects Reviewed from Meta Analysis

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Abstract: Critical thinking is an important element in understanding a subject of Physics, Chemistry, Biology, and Mathematics. Learning outcomes are closely related to critical thinking skills. This study used the meta-analysis method assisted by the JASP program to determine the relationship between critical thinking and learning outcomes in Physics, Chemistry, Biology, and Mathematics. Meta-analysis is used by reviewing research articles published in journals in the range of publication years starting from 2018 to 2023 which are obtained purposively so that there are 20 articles. The results of this meta-analysis show that the relationship between critical thinking and learning outcomes of Physics, Chemistry, Biology, and Mathematics subjects is included in the high category indicated by a correlation effect size (rE) value of 0.891 with a p-value of less than 0.01 at a 95% confidence level.

Keywords: Meta-analysis; Critical thinking; Learning outcomes

Introduction

At this time we are in the era of globalization which is experiencing a huge impact in the field of education. Related to this, in the world of education, there are demands in the era of globalization, including the demands of 21st-century skills, namely Critical Thinking, Communication, Creative Thinking, and Collaboration, where students and teachers are required to have these skills in determining and solving a source of problems faced.

The quality of education can be measured by learning outcomes. Learning outcomes include affective abilities, (acceptance, response, judging, organization, and characterization), cognitive (knowledge, understanding, application, analyzing and synthesizing, and psychomotor (initiation, preroutine, and routine) (Amijaya et al., 2018). One indicator of Bloom's critical thinking tendencies and learning devotions.

The ability to think critically is a thinking process by interpreting development and reasoning using the basis of argument analysis and insight (Mayarni &; Nopiyanti, 2021). Critical thinking patterns are one way of patterns with rational and clear thinking in solving a problem so that this critical thinking ability, if applied in all learning, can provide an increase in learning results because these two things are very related to provide various kinds of behavior patterns both knowledge, understanding, attitudes, skills, and new ideas that can improve learning outcomes (Barka et al., 2020).

said that one factor affecting learning outcomes is the ability to think critically. Student learning outcomes will be maximized if accompanied by critical thinking in solving problems because students' critical thinking gets results and understands the material and questions given.

Some characteristics of students who are able to think critically are as follows: (1) able to understand logical relationships between ideas, (2) able to discuss ideas concisely and precisely, (3) able to identify, build and evaluate arguments, (4) able to evaluate arguments, (5) able to evaluate evidence and able to hypothesize, (6) able to detect inconsistencies and errors in general in reasoning, (7) able to analyze problems systematically, (8) able to identify the relevance and importance of ideas,

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(9) able to assess the beliefs and values held by a person and (10), able to evaluate one's thinking ability (Neti Afrianis, 2019).

One of life's most widely applied abilities is science skills such as Physics, Chemistry, Biology and Mathematics. This ability is included in cognitive abilities, which must involve intellectual abilities and knowledge (Purnomo al., 2022). One of the intellectual abilities and knowledge is that it requires the involvement of critical thinking skills in solving problems through identifying, analyzing, evaluating and concluding (Azizah & Widjajanti, 2019). As has been done in research (Rina et al, 2020) shows a significant correlation between critical thinking and science learning outcomes. (Youllanda et al., 2020) stated that there is a positive correlation between critical thinking skills and Physics learning outcomes. Based on this, it attracts a lot of attention from researchers. Miharja et al. (2019), Ardianto (2019), Nurfitriyanti et al. (2020), Apriani Megawati, (2021), Dellysa Fachriani (2020), Syamsinar (2023), Purnomo (2022), Dwi & Ulan (2021), found a significant relationship between critical thinking and Biology learning outcomes.

These studies have been widely carried out and even carried out continuously, so it is necessary to know the consistency of results over a certain period through a meta-analysis study. Meta-analysis research related to other topics does not yet examine the overall relationship of critical thinking with the Science and Mathematics Subjects. For this reason, an in-depth study is needed to determine the relationship critical thinking skills with science and mathematics learning outcomes through meta-analytic studies. A meta-analysis is needed given the importance of critical thinking knowledge in its internal learning role. This meta-analysis research aims to see the relationship between critical thinking skills and the results of learning science and mathematics at the educational stage.

Method

This study uses the meta-analysis method, which examines several research results in problems similar to this study, namely the relationship of critical thinking with the learning outcomes of Physics, Chemistry, Biology, and Mathematics. The instrument in this study uses a Human instrument, namely the researcher himself who acts as a research instrument. The population in this study was journals obtained online. The research sample uses purposive techniques because the samples taken are by the research theme. The stages carried out in conducting meta-analysis are as follows:

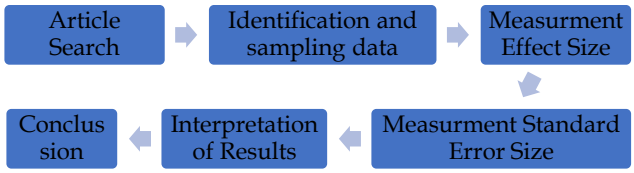

Figure 1. Steps of Research

Article searches were conducted through ports: (1) Google Scholar, (2) Eric, (3) Sinta, and (4) Garuda in publication years ranging from 2018 to 2023. The articles collected were then selected as many as twenty that corresponded to the research objectives. The selected articles were then sampled with the name of the researcher, the title of the researcher's article, the year of publication, the level of research education, the number of respondents, and the value of the correlation coefficient (r). After all sample data is collected, the value of Effect Size (ES) and Standard Error (SE) value will be calculated respectively with the following formula (Retnawati et al., 2018).

$$S= z= 0{,}5 \times In\frac{1+r}{1-r} \text{ and } SE = \sqrt{\frac{1}{N-3}} \quad (1)$$

The effect size of each study and the combined effect were analyzed according to Cohen's (1998) rules as follows:

Table 1 Classification of Effect Size

Interval Effect size (UE)	Classification
0.20 ≥ UE	Low
0.50 ≥ UE > 0.20	Medium
1.00 ≥ UE >0.5	High
1.00 < UE	Very High

Effect Size value and Standard Error value and used for further analysis using JASP software. The output of the analysis results using JASP will be interpreted in accordance with the problem formulation in this study. The results of the meta-analysis and interpretation are the conclusions in this study.

Result and Discussion

Based on the selected articles, as many as 20 research articles discussing the Relationship of Critical Thinking in Physics, Chemistry, Biology, and Mathematics in Indonesia include meta-analysis based on the name of the researcher, the title of the research article, the year of publication, the level of research education, the number of respondents, and the value of the correlation coefficient (r). The following is a table of

data sample search results from 20 published articles with Effect Size and Standard Error output values.

Table. 2 List of articles and Effect Size and Standard Error values.

Researcher	N sample	r	z	vz	Sez
(Youllanda et al., 2020) *	33	0.61	0.60	0.03	0.18
(Husnah, 2017)*	40	0.83	1.74	0.03	0.16
(Ardianto, 2019)*	29	0.24	0.47	0.04	0.20
(Syamsinar, 2023)*	75	0.58	0.55	0.01	0.12
(Aghenia & Nasrudin, 2021)*	34	0.87	2.49	0.03	0.18
(Neti Afrianis, 2019)*	48	0.60	0.59	0.02	0.15
(Purnomo et al., 2022)*	130	0.49	0.21	0.01	0.09
(Apriani Megawati, 2021)*	59	0.82	1.69	0.02	0.13
(Rini Mindi Safitri,, et al., 2020)*	326	0.82	1.69	0.00	0.06
(Fuad et al., 2019)**	118	0.97	10.58	0.01	0.09
(M. Mayarni & Nopiyanti, 2021)	180	0.66	0.74	0.01	0.08
(Mayarni & Yuni Yulianti, 2020)	68	0.72	0.99	0.02	0.12
(Saparuddin, 2021)	50	0.77	1.21	0.02	0.15
(Lathifah et al., 2020)	36	0.85	2.01	0.03	0.17
(Barka at al., 2020)	58	0.49	0.39	0.02	0.14
(Dani et al., 2018)**	137	0.37	0.25	0.01	0.09
(Jodion Siburian, 2019)**	52	0.73	1.01	0.02	0.14
(Dellysa Fachriani, 2020)	238	0.46	0.36	0.00	0.07
(Maya, et al., 2020)**	58	0.74	1.04	0.02	0.14
(Siti al., 2018) *	20	0.60	0.58	0.06	0.24

Description:
* = senior high school level
**= College

Table 2 provides information that there are 2 levels of education in each article sample, namely: 1) high school level and 2) university level.

Table 3. Heterogeneity Test Results

	Q	df	p
Omnibus test of Model Coefficients	91.763	1	<0.00 1
Test of Residual Heterogeneity	305.96 2	19	< 0.001

Note. *p* -values are approximate.
Note. The model was estimated using Restricted ML method.

Table 3 provides information that the 20 effect sizes analyzed are heterogeneous with Q= 305.196 and p-value (0.001) < 5% significance level. Therefore, the Random Effect model can be used to estimate the average effect size of the articles analyzed.

Table 4. Conclusion Effect

Coefficients						
					95% Confidence Interval	
	Estimate	Standard Error	z	p	lower	Upper
intercept	0.093		9.579	< 0.001	0.709	1.074

Table 4 provides information on the results of the analysis with the Random Effect model showing that there is a significant correlation between critical thinking skills and learning outcomes in physics, chemistry, biology, and mathematics subjects with a value of (z = 0.891; p <0.001; 95%). Based on Cohen's classification (1998), the correlation coefficient is in the strong category. This provides sufficient evidence to reject the hypothesis H_0.

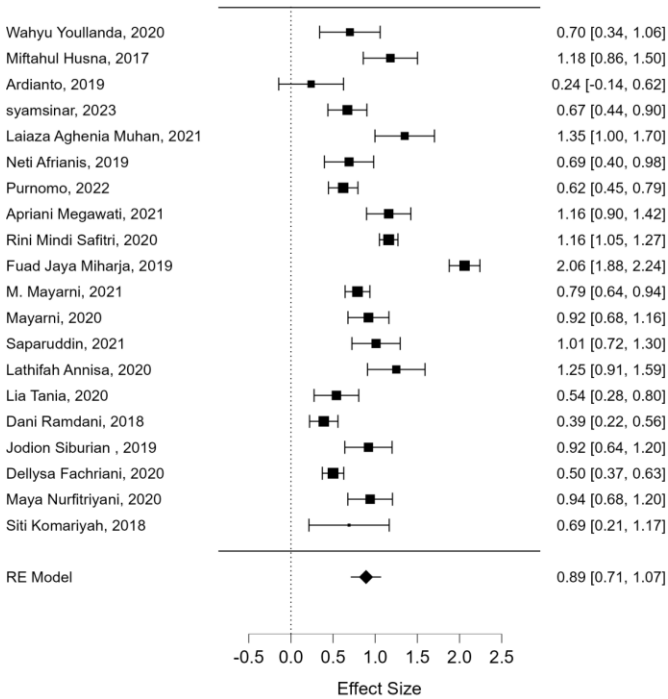

Figure 2. *Forest Plot*

Figure 2 provides information that the effect size values derived from 20 articles have various values ranging from the lowest effect size value of 0.16 to the highest of 2.06. The summary effect size value of 0.81 provides information that 89% of critical thinking has a

relationship with learning outcomes in Physics, Chemistry, Biology and Mathematics.

Table 5. Rank correlation test for Funnel plot asymmetry

	τ	p
Rank test	0.153	0.347

Table 5 provides information about the Rank Correlation value by looking at the τ (Kendall) value of 0.153, which shows the coefficient of correlation between effect size and variance. Funnel Plot analysis, Egger test analysis and Failsafe N analysis were used to see the results of the publication bias test.

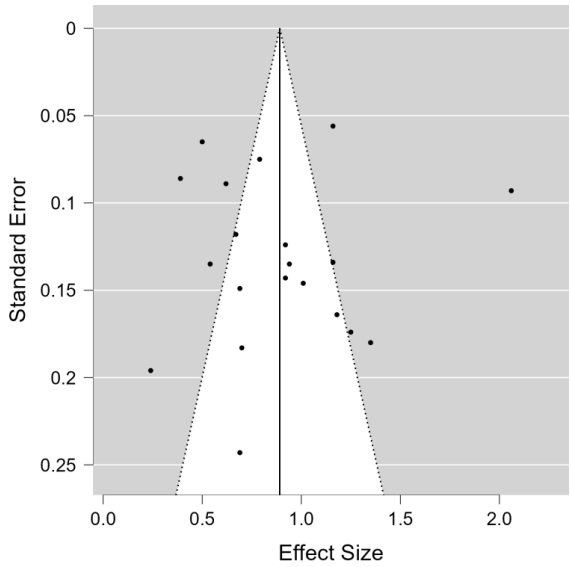

Figure 3. Funnel Plot of Standard Error of each Effect Size

Based on Figure 4, the distribution of standard errors appears irregular, making it difficult to determine whether the funnel plots of the effect sizes of the analyzed studies are systematic or not. Therefore, the inferential analysis of Egger's and Drawe's tests were used to determine this.

Table 6. Regression test for Funnel plot asymmetry (''Egger's test'')

	Z	p
Sei	-0.218	0.827

Table 6 gives the Egger Test p value of 0.827>0.05 confirming that the funnel plot is symmetric. This means that there is no publication bias problem for the meta-analysis.

Table 7. File Drawer Analysist

	Fail-Safe N	Target Significance	Observed Significance
Rosenthal	8639.000	0.050	<.001

Table 7 suggests that 8933 similar publications have biased results. In testing publication bias, it can also be done by looking at the value of the fail-safe N> 5K + 10 where K is the number of studies, and obtained a value of 5 (20) + 10 = 110. So that 8639> 5 (20) + 10 ≈ 7,933> 110. This the findings of the results of this study are very strong because the data analyzed are obtained from valid sources and do not contain bias.

In this research, if the value Effect Size = 0 means that critical thinking skills have no relationship with the learning outcomes of learning science and mathematics. But when Effect Size value ≠0, Critical Thinking skills are related to science and Mathematics learning outcomes.

Table 3 provides information that the z value is 0.9579 and the p-value (0.001) < 5% significance level. This provides sufficient evidence to reject Ho, which means that critical thinking has a relationship with learning outcomes in Physics, Chemistry, Biology and Mathematics. The interpretation of the strength of the correlation coefficient value according to Cohen (199) in (Pallan, 2007) is:

Table 8. Correlation Coefficient Interpretation Guidelines

Coefficient Interval	Relationship Level /Correlation
0.50 < r < 1.00	High
0.30 < r < 0.49	Medium
0.10 < r < 0.29	Low

Based on the value of table 3, it is obtained that the relationship between critical thinking and Learning Outcomes in Physics, Chemistry, Biology and Mathematics is in the high category with a value of r = 0.891. Evaluation of publication bias is carried out to determine whether the data collected and used can be used as a sample that can represent the population. The hypothesis proposed in the publication bias test is as follows:

H_0: *True Effect Size* = 0 (Sample data shows indications of publication bias)
H_1: *True Effect Size* ≠0 (Sample data shows no indication of publication bias)

Figure 2 provides information that the Funnel plot is symmetrical with the support of the Eiger Test analysis in table 5 where the z value is greater than the regression coefficient value of 0.218, and the p-value (0.827) >0.05 which indicates that the sample data is not indicated by publication bias.

Conclusion

Based on the results of a meta-analysis of all studies, it was concluded that critical thinking and learning outcomes of Physics, Chemistry, Biology, and Mathematics in Indonesia have a significant positive correlation with the high category. This represents an rE value of 0.891 with a p-value of less than 0.01 at a 95% confidence level.

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Author Contributions
Jumriani Sultan conceptualized the research idea, designed the methodology, conducted the research process, analyzed the data, and reviewed the literature. Slamet suyanto, and Zulfa safira Ibrahim provided corrections, suggestions, and critical feedback on the manuscript.

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Conflict of Interest
The authors declare no conflict of interest in this research.

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