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The Effect of STEM Integrated Science Innovative Learning Model on Students' Critical Thinking Skills: A Meta-Analysis

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Abstract: This research is a meta analysis. This study aim to analyze the effect of STEM integrated science innovative learning model on students' critical thinking skills. The data collection technique used is the literature review technique, namely by searching and collecting journal articles taken from Google Scholar. Data analysis used quantitative descriptive statistical analysis which aims to obtain effect size values. Based on a meta-analysis of 20 research articles, information was obtained that in general the STEM integrated science innovative learning model has a high influence on students' critical thinking skills with a value of 1.10. If we look at the level of education, education area and learning model, they show that there are significant differences in each field. The greatest impact of STEM is seen at the college level.

Keywords: Critical thinking skills; Learning model; Meta-analysis; STEM

Introduction

The demands of the 21st century emphasize that every individual, including students, has the skills to face changes due to the times. One of the skills required in 21st century education is critical thinking skills (Annisa et al., 2021). These skills require training in the teaching and learning process to achieve the learning objectives, as specified. Improving the skills of students so that they can face the development of the 21st Century which raises abilities such as critical thinking, creative thinking skills and communication skills as the government aspires to at this time. Therefore, the role of innovative educators is needed in order to realize these ideals.

Critical thinking skills are very necessary for students. One of the benefits of critical thinking skills is that students can find out how to get correct and accurate information so that it can be verified. In this way, students can avoid hoaxes, which are currently widely circulating, especially on social media (Santoso, 2021). By thinking critically students will not easily believe before getting evidence and will not share hoax news. Critical thinking skills are very well applied in learning as a preparation for students in facing the challenges of changing times. To be able to optimize critical thinking skills, appropriate learning approaches and models are needed (Santoso, 2021). STEM is an approach to learning that combines the four basic fields of education, namely science, technology, engineering and mathematics. The STEM approach is often combined with learning models (Rahardhian, 2022).

In order for students' critical thinking skills to be optimal, there are several learning models that can be used by educators. A learning model can be an alternative, meaning that each educator can choose any learning model that is suitable and effective for achieving educational goals (Khoerunnisa, 2020). There are various types of learning models that support increasing students' critical thinking, including discovery learning models, PJBL, PJBL-STEM, and guided inquiry (Wastiti, 2019).

Many studies have been carried out in looking at the influence of the STEM integrated learning model. As

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research conducted by Adiwiguna et al. (2019) saw the influence of the STEM-oriented PBL model on critical thinking skills, it has a high influence. Research conducted by Ardianti et al. (2020) entitled the impact of STEM on blended learning to improve critical thinking skills has a very high influence. The research of Dywan et al. (2020) looked at the effectiveness of the STEM-based PjBL model on students' critical thinking skills getting a moderate effect.

The STEM approach with science innovative learning model has been widely used in producing a complete learning process involving various fields of science, so many researchers conduct studies on STEM with science innovative learning models. Based on this research, the results of the influence were different, there were moderate, high and very high. To see the overall effect, a meta-analysis study was carried out to examine the impact of the STEM integrated learning model on students' critical thinking skills. Mapping the results in general of the effect of STEM with science innovative learning models has never been done by previous research. This study aims to see the impact of the STEM integrated learning model on students' critical thinking skills at the educational level, in the field of science studies and on the learning model used. This meta-analysis study is expected to be able to help education, especially natural science educators, in applying the STEM integrated learning model in natural science learning.

Method

This research is a meta-analysis research. Meta-analysis is a research uniting, repeating and processing data obtained from scientific journals that have been published. Meta-analysis has a research method that examines scientific journals in accredited national and international journals. The subjects of this study were 20 national and international journal articles. Some of the article requirements used are: scientific articles regarding the effect of STEM integrated science innovative learning model on students' critical thinking skills. Second, these articles are published in national and international journals that have an ISSN. The stages of this research are shown in the flowchart presented in Figure 1 (Asrizal et al., 2023).

In analyzing the data there are steps, the first determines the type of research and research variables in the article, the second determines the average and standard deviation of the experimental and control classes, and the third determines the effect size value using the formula in Table 1.

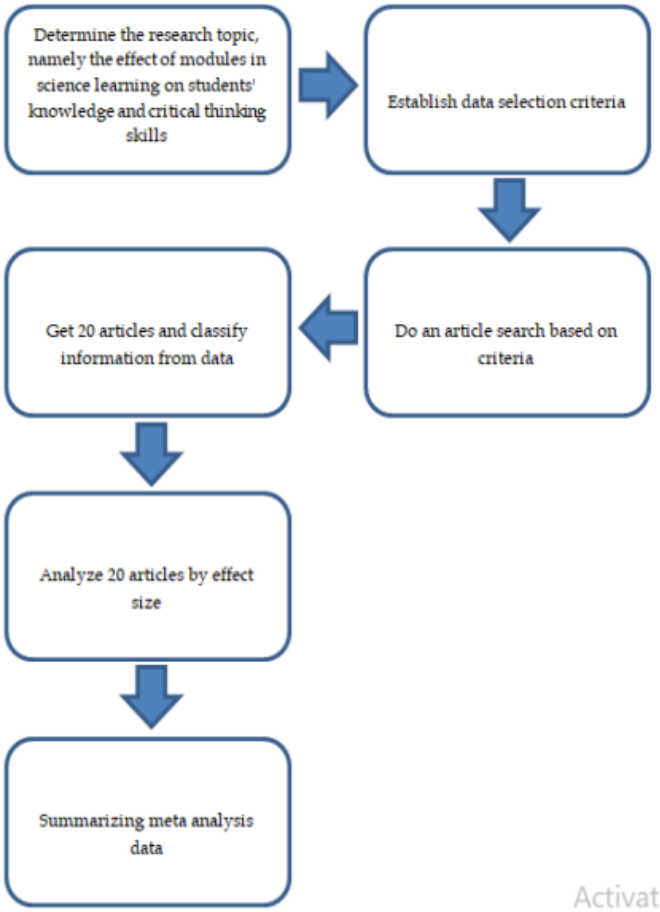

Figure 1. Meta-analysis research flow

Table 1. How to Determine the Effect Size

Statistics Data	Equation
Average in one group	$ES = \frac{\bar{X}_{post} - \bar{X}_{pre}}{SD_{pre}}$
The mean in each group (two groups posttest only)	$ES = \frac{\bar{X}_E - \bar{X}_C}{SD_c}$
Mean in each group (two groups pre-posttest)	$ES = \frac{(\bar{X}_{post} - \bar{X}_{pre})e - (\bar{X}_{post} - \bar{X}_{pre})c}{SD_{pre\,C} + SD_{pre\,E} + SD_{post\,C}}$
t count	$ES = t\sqrt{\frac{1}{n_E} + \frac{1}{n_C}}$

After calculating the effect size value according to the formula, then categorizing the effect size according to Cohen's criteria (1981) as in table 2.

Table 2. Criteria for Effect Size (ES)

ES	Category
0.00 ≤ ES < 0.20	Ignore
0.20 ≤ ES < 0.50	Low
0.50 ≤ ES < 0.80	Medium
0.80 ≤ ES < 1.30	High
1.30 ≤	Very high

Result and Discussion

This research was used to determine the effect of STEM integrated science innovative learning model on students' critical thinking skills. The integration of STEM, involving four disciplines, has proven effective in the context of learning (Bakirci et al., 2022; Kim et al., 2019). To calculate the effect size of the article, data obtained from the appropriate journal is used. The sources that researchers use in collecting data include Google Scholar, natural science education journals and several other journals. The number of articles used in this study is 20 articles selected according to predetermined criteria. First, this research is about STEM-integrated science innovative learning models. Second, the learning model is applied in natural science learning. Third, the learning model has an influence on students' critical thinking skills. The results of calculating the effect size of the 20 articles were analyzed by classifying the articles into several groups. Table 3 shows the grouping of studies based on educational level, subjects and learning models used.

Table 3. Study Grouping

Code	Education level	Subjects	Learning model	ES	SE
A1	Elementary School	Science	Problem Based Learning	0.79	0.25
A2	Senior High School	Physics	Inquiry	0.69	0.25
A3	Elementary School	Science	Project Based Learning	1.02	0.26
A4	Senior High School	chemistry	Problem Based Learning	1.35	0.18
A5	Elementary School	Science	Project Based Learning	0.75	0.39
A6	College	Biology	Problem Based Learning	1.83	0.41
A7	College	Biology	Inquiry	1.69	0.35
A8	Senior High School	Physics	Problem Based Learning	1.36	0.26
A9	Senior High School	chemistry	Project Based Learning	0.96	0.22
A10	Junior High School	Physics	Inquiry	2.02	0.22
A11	Senior High School	Biology	Project Based Learning	0.67	0.24
A12	Junior High School	Physics	Problem Based Learning	1.31	0.25
A13	Junior High School	Science	Project Based Learning	0.73	0.25
A14	Junior High School	Science	Problem Based Learning	0.81	25.0
A15	Senior High School	chemistry	Project Based Learning	0.99	0.10
A16	Senior High School	Physics	Project Based Learning	1.11	0.30
A17	Senior High School	chemistry	Project Based Learning	1.03	0.26
A18	Elementary School	Science	Project Based Learning	0.52	0.25
A19	Junior High School	Science	Problem Based Learning	1.43	0.32
A20	Senior High School	Physics	Project Based Learning	0.98	0.26

Table 3 shows the effect size of the STEM integrated science innovative learning model on students' critical thinking skills of 1.10 which belongs to the high category. Through the results of this analysis, it is known that the STEM integrated learning model has a very high effect on the process of improving students' critical thinking skills. The STEM mapping of students' abilities showed a score of 0.76, which was also in the medium category (Lee et al., 2017). The use of STEM was able to improve students' skills with an effect value of 1.16 (Kazu et al., 2021). The difference in the calculation value of the effect size value is influenced by the factor of the number of articles and the focus of research discussed (Garzón et al., 2019).

PjBL-STEM learning with formative assessments in the experimental class can foster a higher sense of fun than PjBL in the control class (Parno et al., 2022). The results of Nurazmi & Bancong's research (2021) say that students learning using the STEM-integrated PBL model have a significant difference in students' critical thinking skills compared to conventional models. Students' critical thinking skills have a greater increase by using PBL-STEM learning than PBL learning (Putri et al., 2020). This is because in PBL-STEM learning students are encouraged to always be critical in relating the material being studied to the experiences students have and in discovering concepts.

According to Ariyatun et al. (2020) Solving problems requires critical thinking skills. This ability can be identified from several visible characteristics. Critical thinking indicators are that students have the ability to explain simply, develop skills, conclude, conduct research, and establish ways related to critical thinking indicators. Based on the research by Rosyidah et al. (2020) students' critical thinking skills are known to be better after STEM-PjBL learning and authentic assessment. These skills are developed through activities of identifying hypotheses, induction, justification, explanation and evaluation.

The results of research by Fadlina et al. (2021) state that all indicators of students' critical thinking have increased, but there has been a significant increase in the

indicator of argumentation analysis. Critical thinking skills in the argument analysis indicator increase because the use of the STEM-based discovery learning model gives students the opportunity to develop problem identification skills through cases involving the human skeleton. Students can quickly research and understand cases and articulate issues related to the case.

The effect size using the PBL model is 1.27 with a high category. Critical thinking skills in the experimental class have increased because in the PBL-STEM model there are phases where students are trained to find solutions by seeking further explanations in order to be able to improve these abilities (Setyorini et al., 2021). STEM-integrated PBL has an impact on the growth of problem-solving characters (Zulfawati et al., 2022). While the effect size using the PjBL model is 0.88 in the high category. In line with Rahardhian's research (2022) which shows that the application of the STEM-based PjBL model can affect students' critical thinking skills.

The effect size through the inquiry model is 1.47 with a very high category. This is in line with Dafrita & Nawawi's research (2022) which states that integrating STEM into inquiry learning is also believed to be able to positively influence the development of students' critical thinking skills. Through this learning, students are allowed to empower their scientific process skills and scientific information to decide to use the most appropriate method or technology to solve problems that arise from the inquiry process. In the process, students are trained to identify problems, propose hypotheses, choose the right way with the help of technology to carry out investigations, and collect and analyze data as a basis for conclusions. From the research results of Santoso et al. (2021) it is known that learning using the inquiry model combined with STEM has a significant influence on students' critical thinking abilities.

Table 3 shows the effect size of the STEM integrated science innovative learning model on critical thinking skills at the elementary school level of 0.77 and belongs to the medium category. The STEM-based PJBL learning model has an impact on critical thinking in elementary school students (Dywan et al., 2020). There are other problems that also affect students' critical thinking besides the learning model that is applied. Students' personal skills or abilities are an important element in the development of critical thinking. With any learning model, learning is easily embraced because students become more proficient. Meanwhile, at the junior high school education level it was 1.26 and classified in the high category. From the research results of Cahyaningsih et al. (2018) said that STEM-PBL-based natural science learning has a significant effect on the critical thinking of class VIII students.

At the high school education level, it gives an effect size of 1.01 and belongs to the high category. In accordance with research by Hasanah et al. (2021) which said that identifying PBL learning models combined with STEM-based worksheets can improve critical thinking in high school students. Meanwhile, at the college level, it has an effect size of 1.76 and belongs to the very high category. From the results of Dafrita & Nawawi's research (2022), it can be concluded that the critical thinking skills of Biology Education students have a positive and significant effect on using STEM integrated inquiry. Table 5 shows the effect size value of the STEM integrated learning model on students' critical thinking skills based on subjects.

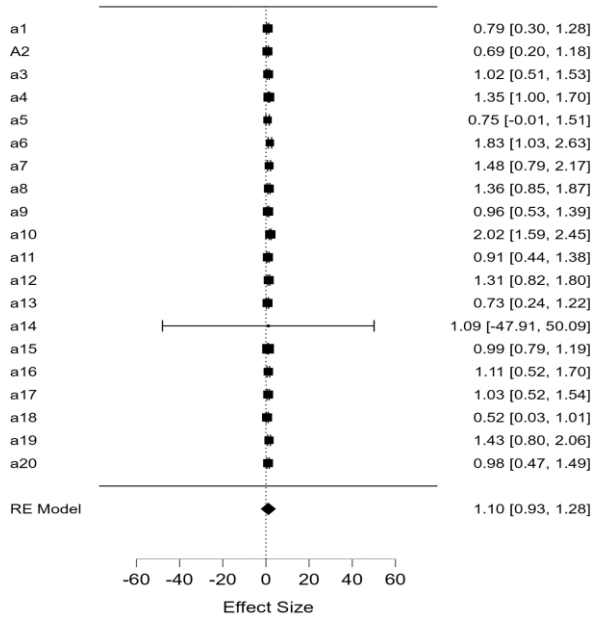

Figure 2. Forest plots

The average effect size value is 1.10 in the range 0.93 to 1.28 at the 95% confidence level. The average effect size value is in the large category.

Table 4. Heteogenicity Test

Variable	Value	95% Cl (level of confidence)	
k	20		
Q	41.681		
d	1.104		
z	12.632	0.933	1.276
τ^2	0.079	0.015	0.230
τ	0.281	0.122	0.479
I^2 (%)	57.826	20.566	80.003
H^2	2.371	1.259	5.001

D= average effect size
Q= heterogeneity test value
τ^2, τ, I^2 (%), H^2 = result of high effect size value

Table 5. Moderating Effects on Educational Level, Educational Sector, and Model

Moderator	k	Effect size	95% CI		Qb	p-Value
			Lower	Upper		
Level of education					1.86	0.0008
ES	4	0.77	0.5	1.036		
JHS	3	1.379	0.838	1.919		
SHS	9	1.038	0.912	1.164		
University	2	1.63	1.106	2.149		
Education Area					15.013	0.0005
Biology	3	1.332	0.783	1.881		
Physics	6	1.257	0.878	1.636		
Science	7	0.845	0.613	1.077		
Chemistry	4	1.069	0.886	1.253		
Learning Model					9.515	0.02
Inquiry	3	1.40	0.611	2.189		
Problem Based Learning	7	1.289	1.073	1.505		
Project Based Learning	10	0.934	0.805	1.062		

Qb is a test of heterogeneity between educational levels. P-value <0.05 means there is a significant difference in each field. 95% Cl means at the speed level 95% the magnitude of the effect size value. Publication bias relates to effects that are not statistically significant (Borenstein et al., 2010). In meta-analyses, publication bias can result from a variety of factors (Egger et al., 1997). Methods used to detect publication bias include funnel plots, file drawer analysis, and Egger's regression, as shown in tables below.

Table 6. Publish Bias Test through Egger Test

Regression test for Funnel plot asymmetry ("Egger's test")		
	z	p
sei	0.346	0.729

Table 7. Publish Bias Test through Plot Asymmetry

Rank correlation test for Funnel plot asymmetry		
	Kendall's τ	p
Rank test	0.226	0.177

Table 8. Publish Bias Test through File Drawer

File Drawer Analysis			
	Fail-safe N	Target Significance	Observed Significance
Rosenthal	2753.000	0.050	< .001

Based on the results of the published bias test through the funnel plot, the distribution of the data is difficult to observe for its symmetry. So to conclude the symmetry is done through a comparison of the p value. If the value of p <0.05 then there is a public bias. In the asymmetric etstd eger test, it shows a value of p> 0.05, which means that there is no publish bias. Furthermore, through the value of fal safe n with a standard passing grade of 5K + 10. K is the number of articles analyzed. The value of failsafe N is greater than the standard value, so there is no publish bias.

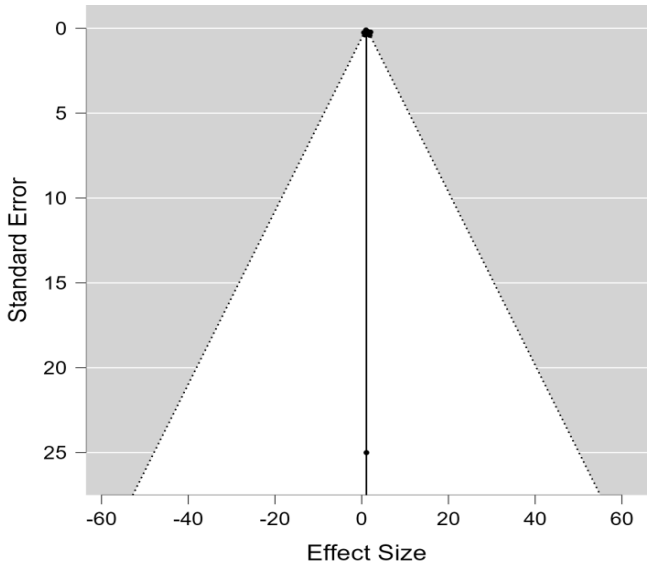

Figure 3. Funnel plots

Conclusion

Based on a meta-analysis of 20 research articles, information was obtained that in general the STEM integrated science innovative learning model has a high influence on students' critical thinking skills with a value of 1.10. If we look at the level of education, education area and learning model, they shows that there are significant differences in each field. The greatest impact of STEM is seen at the college level. Apart from that, research discussing innovative integrated science learning models is often found in international journals.

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Conflicts of Interest
The author's interest in publishing this article is for research output needs in the form of publication in scientific journals as proof of the required performance. There is no conflict of interest in carrying out and publishing this study.

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