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The Effect of the STEM Approach on Students Critical Thinking Skills: A Meta Analysis

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Abstract: Indonesia's. STEM education is one method that may help students succeed in the modern world. This study set out to assess the quality of prior work that looked at how STEM education affected students' capacity for critical thinking. Level of education and learning model were the moderators taken into account in this research. In order to get quantitative data, the researchers used meta-analysis to determine the impact size of each study that was relevant. Journals acknowledged with an ISSN between 2020 and 2025 were the criterion used to look for national and international journals that have been researched by previous researchers. According to the impact size study of STEM education on students' critical thinking abilities, which was conducted across all educational levels and models, the findings were in the high category. This suggests that students' critical thinking abilities may be enhanced across all educational levels via the use of the STEM method in the classroom.

Keywords: Critical thinking skills; STEM

Introduction

The foundations of education in the twenty-first century lie in science and technology. The goal here is to provide the next generation the tools they need to succeed in a global economy. Everyone in the modern day has to be able to think critically, work together, communicate effectively, and be creative (Chusni et al., 2020). Learning in the twenty-first century must be student-centered, collaborative, relevant to real-world phenomena, and societally contextualized (Asrizal et al., 2018). According to Novovianti et al. (2023), one way to teach or enhance abilities that are relevant in the modern world is to use creative learning practices. Educating for the information technology and humanitarian sectors in the modern day requires a synthesis of traditional academic disciplines with new ways of thinking and doing. Critical thinking, problem solving, communication, collaboration, innovation, creativity, metacognition, and information literacy are some of the thinking skills that students in the 21st century are expected to acquire (Mardhiyah et al., 2021; Muliyadi et al., 2026; Rosyidah et al., 2020; Saefullah et al., 2021; Sholikhah et al., 2024; Ulhaq et al., 2020).

The STEM fields-science, technology, engineering, and mathematics-form an educational framework that unites these four disciplines (Alatas et al., 2021). Progress in Science and Technology (IPTEK) may be traced back to these four fields. According to Oktavia (2019), students who pursue STEM education are expected to be ready for the ever-changing globalized period. Incorporating STEM into the classroom helps inspire students to take an active role and learn to solve complex issues by drawing from a variety of sources (Agustin et al., 2026; Muttaqiin, 2023). A study conducted by Mahombar et al. (2023) and Rahardhian (2022) found that incorporating the PjBL paradigm into STEM education improved students' ability to think critically and creatively. Adiwiguna et al. (2019) found that students' critical thinking abilities were simultaneously impacted by the STEM-oriented PBL model's deployment. In order to produce top-notch human resources, Hermansyah (2020) found that STEM-based scientific education with the use of ICT may

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greatly enhance 21st-century capabilities. Because it places lessons in real-world situations and promotes critical thinking, creativity, communication, and teamwork, electronic LKPD that follows the STEM method may help students develop 21st-century abilities (Wedy et al., 2024).

Table 1. Trigger Questions in Research

Number	Trigger Questions
1	What is the impact of the STEM approach on students' critical thinking skills?
2	Who is the research subject?
3	What learning model is used?

In contrast, Ashidiq et al. (2024) found no statistically significant difference between the control and experimental groups when it came to STEM learning treatments that included the PjBL model (Khoiriyah et al., 2018). Noufal (2022) found no evidence of a statistically significant improvement in the sample they examined as a result of the STEM intervention. Similarly, studies examining the acquisition of scientific and mathematical concepts yielded contradictory findings. Although some subgroups demonstrated progress, there was no guarantee of statistically significant group differences (Sahabudin et al., 2024). Additional moderator analysis is recommended due to the substantial difference across studies that was found in many meta-reviews (Sastra et al., 2022).

The purpose of this research was to assess the effect of STEM fields on students' capacity for critical thinking by reviewing and analyzing several modernizing elements. Multiple steps were taken to assess the data that was gathered from different sources.

Method

This research was conducted through a literature review of several articles from previous studies. The method used was a quantitative descriptive meta-analysis. The data collection instrument used was coding. The variables used included: researcher's name, year, educational level, learning model, and teaching materials.

Here are the steps to follow: 1) decide on a title for the research; 2) gather as many articles as needed; 3) organize the articles into groups; 4) summarize the data; 5) code the data for analysis; 6) calculate the effect size (ES) from the collected data; and 7) draw conclusions from the data (Listyaningrum et al., 2024).

Determine the Title of the Research

This first stage is to determine the focus of the research to be conducted. Several related questions relate to the chosen topic, namely STEM. The following are some of the questions that serve as research parameters.

Collect as Many Articles as Needed

Currently, publications pertinent to the study subject are gathered using the Google Scholar search engine and the publish or perish tool. Using the following parameters: journals, 2019-2025 times frame, citations and patents, 50 maximum results per search, and the following keywords: STEM, critical thinking, and scientific education.

Grouping the Articles Obtained

This step involved searching 50 articles. Twenty articles related to the research title were then identified. These articles were then placed in a folder to distinguish them from the other articles.

Summarizing Research Data

In the next step, the obtained articles were summarized in a Word file, detailing the following: article number, author's name, journal name, research title, research type, and conclusions. Of the 20 articles obtained, two were unrelated to science. Therefore, to replace these articles, two related articles were searched again, taken from the references of the previously obtained articles.

Coding in Analyzing Data

Coding is based on the articles obtained first and then the last. Coding uses the prefix J followed by a number. Like article 1 is named with J1, article 2 is named with J2 and so on.

Analyzing the Effect Size of Data Collection Results

Then the 20 articles were analysed for their effect sizes one by one using the statistical parameters listed in Table 2 below. Table 3 below shows the results of the subsequent grouping of articles according to the effect size criteria, which were determined after each article's impact size analysis.

Table 2. Equation for Determining Effect Size (Listyaningrum et al., 2024)

Statistics	Equations	Formula
Average in one group	$ES = \frac{X_{post} - X_{pre}}{SD_{pre}}$	Fr-1
Average in each group (two groups posttest only)	$ES = \frac{X_E - X_C}{SD_C}$	Fr-2
Average in each group (two groups pre-post test)	$ES = \frac{(X_{post} - X_{pre})E - (X_{post} - X_{pre})C}{\frac{SD_{preC} + SD_{preE} + SD_{postC}}{3}}$	Fr-3
Chi-square	$ES = \frac{2r}{\sqrt{1} - r^2}$	Fr-4
T test	$ES = \sqrt{\frac{1}{n_E} + \frac{1}{n_C}}$	Fr-5
P value	CMA (Comprehensive Meta-Analysis Software)	Fr-6

Table 3. Effect Size Criteria

Effect Size (ES)	Category
0 ≤ ES ≤ 0.2	Low
0.2 ≤ ES ≤ 0.8	Medium
ES ≥ 0.8	High

Summarizing the Results of Data Analysis

This study will finish with the following sections:1) article information; 2) effect size of each article and the formula used; 3) STEM based on education level; and 4 STEM based on the learning model employed, all derived from data analysis of the articles received.

Result and Discussion

Journal searches were conducted using Publish or Perish, using "STEM," "critical thinking skills," and "sciencelearning" for the years 2020 to 2025. Of the 50 articles searched, 20 were found to be quite relevant to Modul the research title. After reviewing each article, two articles were found to be unrelated to science subjects, so a re-search was conducted for two replacement articles using Google Scholar.

Table 4. Below Provides Information on 20 Papers that are Pertinent to the Topic of Students' Critical Thinking Abilities and How They Relate to STEM

Code	Author	Year	Education Level	Learning Mode
J1	Sholeha et al.	2025	Elementary	PjBI
J2	Ashar et al.	2023	Elementary	
J3	Nailinda et al.	2025	Elementary	
J4	Pratiwi et al.	2025	Junior High School	Inkuir
J5	Kusyanto et al.	2022	Junior High School	
J6	Ariyatun et al.	2020	SMA	PBI
J7	Novitasari et al.	2024	MA	PjBI
J8	Parno et al.	2022	Senior High School	PjBI
J9	Evcim et al.	2021	Junior High School	
J10	Maryani et al.	2024	Elementary	CTI
J11	Ashidi et al.	2024	Junior High School	PjBI
J12	Solikhah et al.	2024	Junior High School	Modu
J13	Wiratman et al.	2023	Elementary	PjBI
J14	Isdianti et al.	2021	Junior High School	Inkuir
J15	Nurazmi et al.	2021	Senior High School	PBI
J16	Parno et al.	2020	Senior High School	
J17	Retnowati et al.	2020	Junior High School	
J18	Afifah et al.	2020	Senior High School	PjBI
J19	Santoso et al.	2021	Junior High School	Inkuir
J20	Dewi et al.	2023	Elementary	PjBI

The STEM method may be used throughout different educational levels, from elementary to high school, as seen in Table 4 above. It is also possible to combine the STEM method with other forms of education.

An effect size formula that was suitable for each of the 20 publications mentioned above was used for

analysis. Table 5 below displays the effect sizes that were achieved.

The STEM technique had a large impact size, as shown in Table 5, with an average of 1.96. This suggests that students' critical thinking abilities may be enhanced across all educational levels via the use of the STEM approach to learning (Widyasmah & Herlina, 2020). There are a number of learning paradigms that it may be mixed with, including as inquiry, PBL, PjBL, and CTL. Table 6 displays the results broken down by grade level for how the STEM approach affected students' critical thinking abilities. At the same time, Table 7 shows how the STEM approach, according to the learning model, affects students' critical thinking abilities.

Table 5. Effect Size Data Processing Results for Articles

Code	Effect Size	Criteria	Formula
J1	0.85	High	Fr-5
J2	1.11	High	Fr-2
J3	2.49	High	Fr-3
J4	1.74	High	Fr-1
J5	0.67	Medium	Fr-4
J6	1.37	High	Fr-5
J7	1.41	High	Fr-3
J8	1.23	High	Fr-3
J9	0.33	Medium	Fr-2
J10	3.32	High	Fr-1
J11	0.37	Medium	Fr-3
J12	1.51	High	Fr-1
J13	2.81	High	Fr-1
J14	7.86	High	Fr-1
J15	3.85	High	Fr-2
J16	1.96	High	Fr-2
J17	1.45	High	Fr-2
J18	0.51	Medium	Fr-4
J19	3.61	High	Fr-3
J20	0.75	Medium	Fr-2

Table 6. STEM Approach Effect on Students' Critical Thinking Skills Based on Education Level

Education Level	Journal Code	Effect Size	Average Effect Size	Category
SD	J1	0.85	1.89	High
	J2	1.11		
	J3	2.49		
	J10	3.32		
	J13	2.81		
	J20	0.75		
SMP	J4	1.74	2.19	High
	J5	0.67		
	J9	0.33		
	J11	0.37		
	J12	1.51		
	J14	7.86		
	J17	1.45		
	J19	3.61		
SMA/MA	J6	1.37	1.72	High
	J7	1.41		
	J8	1.23		
	J15	3.85		
	J16	1.96		
	J18	0.51		

From the data in Table 6, it is clear that the STEM approach has a significant impact on students' critical thinking abilities across all grade levels. The average impact size was 2.19 at the middle school level, the lowest at the high school/vocational school level, and the greatest at the elementary school level. But impact sizes were strong across the board for elementary, middle, and high schools.

Table 7. STEM Approach Effect on Students' Critical Thinking Skills Based on the Learning Model

Learning Model	Journal Code	Effect Size	Average Effect Size	Category
Inquiry	J4	1.74	4.40	High
	J14	7.86		
	J19	3.61		
PjBL	J1	0.85	1.13	High
	J7	1.41		
	J8	1.23		
	J11	0.37		
	J13	2.81		
	J18	0.51		
	J20	0.75		
CTL	J10	3.32	3.32	High
PBL	J6	1.37	2.61	High
	J15	3.85		

Combining the STEM method with the inquiry learning model, PBL, and PjBL results in a large category impact size, as shown in Table 7. An average impact size of 4.40 is achieved when STEM is integrated with the inquiry learning methodology. The average effect size when paired with the PjBL model is 1.13. An average impact size of 3.32 is achieved when the CTL model is integrated. In addition, the average impact size when using the PBL model is 2.61. By integrating STEM with the inquiry methodology, we get the largest average impact size value. Plus, the PjBL model brings the lowest value to 1.13.

Conclusion

Effect size study of 20 papers on the STEM approach's impact on students' critical thinking abilities revealed, on average, a large effect size. The articles' educational levels and the extent to which they integrated different learning methods were different. The average impact size was greatest for students in junior high or above and lowest for those in senior high

or below when the data was further stratified by degree of education. The inquiry model had the largest average effect size when the results were stratified by learning model, while the PjBL model had the smallest. It follows that students' critical thinking abilities may be enhanced across all grade levels by using the STEM method. Similarly, the STEM method may help students develop better critical thinking abilities when paired with other learning paradigms.

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No conflict of interest has been disclosed by the writers.

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