



# The Effect of STEM-Based Differentiated Learning to Improve Students' Critical Thinking Skills: A Meta-Analysis Study

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**Abstract:** This study aims to determine the effect of differentiated learning to improve students' critical thinking skills. The type of research is meta-analysis. The samples of this study came from 13 national and international journals. The process of searching for research samples through Google Scholar, ScienceDirect, Eric, Springer, Plos ONE, MPDI, and ProQuest databases. The inclusion criteria were Research must be national and international journals indexed by SINTA, WOS, and Scopus; Research must be experimental or quasi-experimental; Research from national and international journals published in 2019-2023; 4) Research has a relationship with research variables; 5) Research data must have t, f, and standard deviation values. The data selection process is the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method. Data analysis is statistical analysis with the help of JSAP. The results concluded that the average effect size value of the whole study was 0.892 with high criteria. This finding shows that STEM-based differentiated learning has a significant effect on students' critical thinking skills.

**Keywords:** Differentiated Learning; STEM; Critical Thinking; Meta-analysis

## Introduction

Critical thinking skills are skills that guide students to think analytically and systematically in solving a problem (Chowning et al., 2012; Snyder & Wiles, 2015; Elfira et al., 2023; Yousef, 2021). Critical thinking skills help students to think at a higher level in learning (Ichsan et al., 2023; Ayuningrum et al., 2015; Anindyta & Suwarjo, 2014). Bagus et al., (2022) Critical thinking skills encourage students to be more active and creative in learning activities. Furthermore, critical thinking helps students to improve their ability to analyze problems (Allison & Pan, 2011; Hohmann & Grillo, 2014; Hamengkubuwono et al., 2016).

The reality at school, students' critical thinking skills are still relatively low (Maksum, 2021; Hariyanto et al., 2022). This is influenced by teacher-centred learning (Habibah et al., 2022; Zulkifli et al., 2022), Students are unable to solve questions that lead to the level of analysis and evaluation (Nurtamam et al., 2023; Ariani, 2020; Supriyatno et al., 2020). Teachers only

deliver material and students only listen so that students become passive in learning (Alabdulaziz, 2022; Astika et al., 2013). Next, (Al-fikry & Syukri, 2018) stated that teachers have not been able to use learning models that can involve students more actively and think critically in learning. Therefore, teachers need to improve learning models that can encourage students' critical thinking skills.

Differentiated learning model is a learning model that involves students more actively in learning so that they can develop critical thinking skills (Liliawati et al., 2022; Papanthymou & Darra, 2022). Gupta et al., (2023) stated that differentiated learning makes the learning process student-centred. Differentiated learning helps students more easily demonstrate the subject matter (Konstantinou-katzi et al., 2012; Bal, 2016; Bikić & Maričić, 2016). Furthermore, differentiated learning allows students to learn according to their interests (Sitorus et al., 2022; Haelermans, 2022). Research results (Stavrou & Koutselini, 2016) Differentiated learning

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helps improve cognitive competence that can encourage students' critical thinking skills in learning.

Furthermore, STEM-based differentiated learning is one of the effective learning models in encouraging students' critical thinking skills. STEM is a learning approach that combines Science Technology Engineering and Methematic in the learning process (Rahming, 2022; Putra et al., 2023; Zulyusri et al. , 2023; Mataka et al., 2020; Aldahmash et al., 2019). STEM learning is able to encourage students to be more creative and innovative in learning (López-belmonte & González, 2022; Baran et al., 2021; Siew & Ahmad, 2023; Sevimli & Ünal, 2022). The STEM approach trains students in improving scientific attitudes that can stimulate students' critical thinking skills in learning (Salvatierra & Cabello, 2022; Uzun, 2023; Ak et al., 2022).

Research results before Thapliyal et al., (2021) Differentiated learning models can increase students' interest and motivation in learning so as to foster critical thinking skills. Research Gheysens et al., (2020) Differentiated learning can develop students to be more independent and active in learning. Next, (Balgan et al., 2022) Differentiated learning helps students to work together so that students are directly involved in learning activities. But in fact, there are many studies on differentiated learning, there are still few that describe the effect size of the STEM-based differentiated learning model on the remaining critical thinking skills. Based on these problems, this study aims to determine the effect of differentiated learning to improve students' critical thinking skills.

**Method**

*Research Design*

This study is a type of meta-analysis research. Meta-analysis is research that analyzes previous studies that can be analyzed with statistics (Suharyat et al., 2022; Supriyadi et al., 2023; Kazu & Yalcin, 2022; Donolato et al., 2022; Rahman et al., 2023; Santosa et al., 2021). This meta-analysis study aims to determine the effect of STEM-based differentiated learning on critical thinking skills. According to Glass in (Ulum, 2022; Betthäuser et al., 2023) The steps of meta-analysis are literature search process and inclusion criteria; coding the studies; calculating the effect size value of each study; determining the moderate effect of study characteristics.

*Literature search process and inclusion criteria*

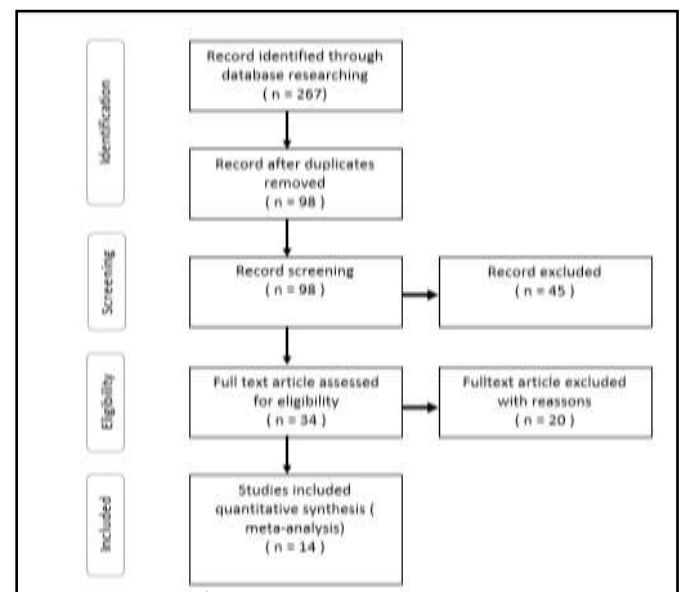
The process of searching research literature through google scholar, ScienceDirect, ProQuest, ERIC, Web of Science, DOAJ, Springer, Plos ONE and Emerald databases. The process of selecting research using the Preferred Reporting Items for Systematic Reviews and

Meta-Analysis (PRISMA) method. Furthermore, the inclusion criteria in this study can be seen in Table 1.

**Table 1.** Inclusion Criteria

Criteria	Inclusion
Publication Period	Journal published in 2018-2023
Publication type	International and national journals or publications indexed by SINTA, Web of Science and Scopus.
Language	Indonesian and English
Design Research Result	Experiment or quasi-experiment Critical thinking skills
Accessibility	Full text
Data	Sample size, Standard deviation and mean value.

Furthermore, the keywords used for the data source search process are differentiated learning model, STEM approach and critical thinking skills. Overall, the data source search resulted in 267 studies. Subsequently, 98 studies were eliminated due to duplication and 45 studies were deleted because they did not fit the research problem. Taking into account the inclusion criteria, 34 studies were not suitable. Thus, 14 studies were selected according to the inclusion criteria. The complete process of selecting research data can be seen in Figure 1.



**Figure1.** PRISMA Flow Diagram

*Data Coding*

Coding in meta-analysis is important in collecting and analyzing data (Taşdemir, 2022). The research instrument used a coding category sheet. The coding in this meta-analysis describes publication characteristics consisting of publication year, country of origin, study

sample size (N), correlation value (rxy), t value, F value, and publication type. The complete comparison of 14 studies based on N, r, t, and F values can be seen in Table 2.

**Table 2.** Comparison of 14 Studies Based on N, r, t and F Values

Journal Type	Year	Sampel	N	R	T	F
A1	2021	SMP	40		0.891	
A2	2020	SMA	35		6.010	
A3	2020	SMA	30		3.540	
A4	2023	SMP	30		0.612	
A5	2019	SMP	40		0.720	
A6	2019	SMA	48		7.772	4.912
A7	2021	SMA	38	0.614	0.375	
A8	2023	SD	27		9.174	
A9	2020	SD	30		0.971	
A10	2019	SMA	24		0.383	
A11	2018	SMA	42		8.107	
A12	2018	SMP	50	0.512	0.769	
A13	2020	SMP	70		5.314	
A14	2021	SMA	36		3.082	

*Data Analysis*

The data analysis process in this study calculated the effect size value of each study, each publication, heterogeneity, and combined effect size. Data analysis in the study was carried out with the help of the JSAP application. Furthermore, the data analysis of this study by calculating the value of Cohen's d. Cohen's (1998) Effect size criteria can be seen in Table 3.

**Table 3.** Criteria Effect Size Cohen's

Effect Size	Criteria
0.20- 0.49	Weak Effect
0.50 - 0.79	Moderate effect
≥ 0.80	Strong effect

Sumber: Cohen's dalam (Kazu & Yalçın, 2021; Taşdemir, 2022)

**Result and Discussion**

*Results*

Based on 14 studies that met the inclusion criteria, a heterogeneity test was conducted. Furthermore, studies that did not have an r value, the t or F value was converted to an r value. The results of the heterogeneity test can be seen in Table 4.

**Table 4.** Heterogeneity Test Results

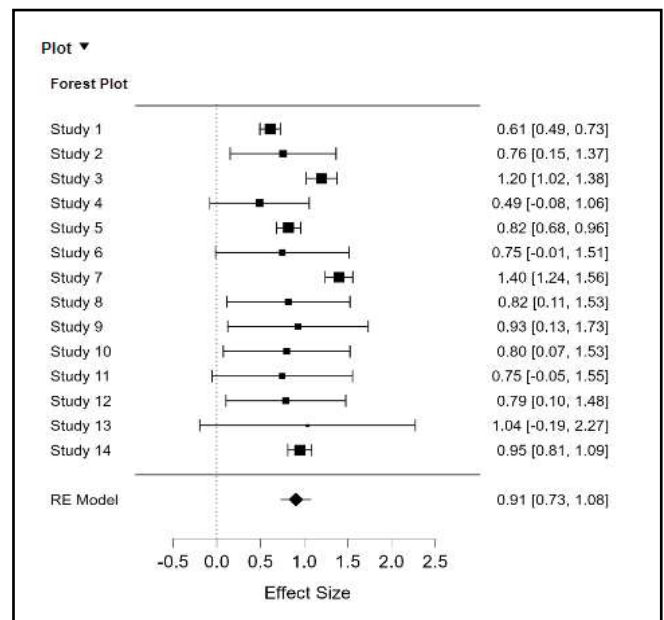
	Q	df	P
Omnibus test of Model Coefficients	13.190	1	< 0.01
Test of Residual Heterogeneity	52.467	13	< 0.01

Based on table 4. The results of the heterogeneity test with the JSAP application Q value = 52.467 with p < 0.01 so it can be concluded that 14 studies are heterogeneously distributed. Furthermore, conducting a summary effect analysis, the average effect size value and publication bias are calculated with a random effect model. Summary Effect test results or the average effect size value can be seen in Table 5.

**Table 5.** Summary Effect or Average Effect Size of Research

	Estimate	Standard Error	Z	P	Lower	Upper
Intercept	0.892	0.053	4.175	0.000	0.274	0.392

Table 5 showing the results of the analysis with random effect model explains that there is a significant influence of STEM-based differentiation learning model with students' critical thinking skills. The effect of STEM-based differentiated learning model on students' critical thinking skills with high criteria (rRE = 0.892). Furthermore, the results of this meta-analysis research are also presented in the form of forest plot. Forest plot functions to determine the estimated combined effect by paying attention to points at certain intervals. The research forest plot can be seen in Figure 2.



**Figure 2.** Forest Plot

Figure 1 shows the forest plot of the effect size of the analyzed studies ranging from 0.49 - 1.40. The next step is illustrated with a funnel plot. Funnel plot is a distribution in meta-analysis to determine the

publication bias of each analyzed study (Salvatierra & Cabello, 2022). The funnel plot can be seen in Figure 3.

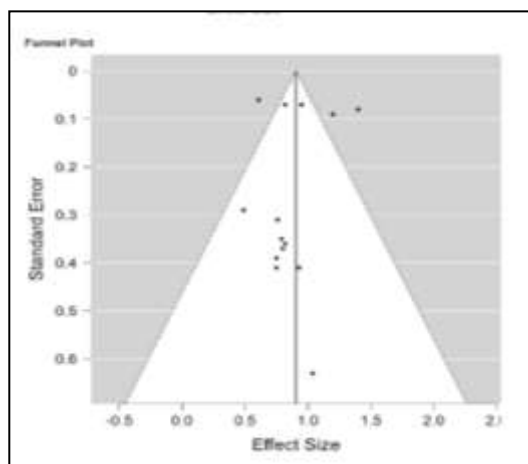


Figure 3. Funnel Plot Standard Error

Based on table 3. The funnel plot shows no clear publication bias. Therefore, it is necessary to analyze using the Egger test. The results of the Egger test in this meta-analysis can be seen in Table 6.

Table 6. Egger Test Results

	Z	P
Sei	2.160	0.001

Based on Table 6, the Z value is 2.160 or  $p < 0.001$ . This result shows that the funnel plot is symmetrical. Therefore, the studies in this meta-analysis are resistant to publication bias.

Discussion

From the analysis of 14 studies conducted by meta-analysis, it shows the effect of STEM-based differentiated learning model on students' critical thinking skills with ( $p$ -value  $< 0.05$ ). STEM-based differentiated learning model encourages students to be more active and innovative in learning (Thapliyal et al., 2021). This result is supported by research (Brodersen & Melluzzo, 2022) Differentiated learning helps foster cognitive abilities that can foster students' critical thinking skills. Furthermore, the differentiation model helps teachers understand students' ability to learn (Tapper & Horsley, 2017; Dalila et al., 2022).

(Jager, 2016) STEM-based differentiated learning model can help students understand the material faster in the learning process. Differentiated learning model can improve students' learning outcomes and thinking skills (Handa & Handa, 2019; Kurniasih & Priyanti, 2023; Chiat & Farhana, 2021; Ma et al., 2010). Furthermore, in Table 5. The estimate value is ( $rRE = 0.892$ ) with high criteria, standard error 0.053 and Z value 4.175 or  $p < 0.00$  so that the application of the

STEM-based differentiated learning model has a high positive effect on students' critical thinking skills. Thinking skills play an important role for students in solving problems in life (Anggraini & Wahyuni, 2021; Ilkorucu et al., 2022; Boonsathirakul & Kerdsomboon, 2023). In addition, critical thinking skills help students think deeply and analytically in learning.

Furthermore, Figure 2 shows a forest plot illustrating the publication bias of the studies in the meta-analysis. The funnel plot shows that there is no clear publication bias in some of the studies that were meta-analyzed. Therefore, it is necessary to conduct the Egger test to determine the publication bias of the research. Table 6. shows the value of ( $Z = 2.160$ ) or  $p$ -value  $< 0.05$  so that the analyzed studies are resistant to publication bias. Publication bias in meta-analysis research is influenced by many factors (Aybirdi, 2023; Demir & Doğuyurt, 2022). Thus, it is important to analyze publication bias in meta-analyzes (Dabiriyantehrani & Yamini, 2021). So, the research analysis of STEM-based differentiated learning model is one of the solutions in encouraging students' critical thinking skills in learning.

STEM-based differentiated learning model shapes students' character and learning style according to their talents (Sitorus et al., 2022). According to (Morgan et al., 2014) the application of differentiated learning models helps teachers more easily direct students according to their learning talents so that students can increase their thinking potential. (Santoso & Istiyono, 2022) STEM-based differentiated learning model can help students in mastering and understanding learning technology. The STEM approach combines science technology engineering and maths to train students' critical and creative thinking skills in learning (Hacioglu & Gulcan, 2021). The existence of a STEM-based differentiated learning model makes students more critical in solving a problem in learning.

Conclusion

From this research, it can be concluded that the average effect size value of the entire study is 0.892 with high criteria. This finding shows that STEM-based differentiated learning has a significant effect on students' critical thinking skills. Furthermore, the STEM-based differentiated learning model helps students access learning information that can support students' critical thinking skills in learning. Not only that, the STEM-based differentiation model makes students more active and creative in learning.

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#### Author Contributions

Researchers play a role in collecting, selecting and analyzing data to complete this research.

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#### Conflicts of Interest

Authors declare no conflict of interest.

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