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Effectiveness of STEM Learning Based on Design Thinking in Improving Critical Thinking Skills in Science Learning: A Meta-Analysis

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Abstract: This study aims to determine the effectiveness of Design Thinking-based STEM learning in improving students' critical thinking skills in science learning. This research is a type of meta-analysis research. Data sources in the study came from 100 national and international journals published from 2017-2023. Search for data sources through google scholar, Eric, Wiley, Taylor of Francis, Sciencedirect, and ProQuest. Data collection techniques through direct observation through the journal database. The keywords used in the search are STEM model, Design Thinking, Critical thinking skills and Science learning. Data analysis technique is quantitative descriptive analysis with JSAP application. The effect size of each study on the STEM learning model based on design thinking in science learning is 0.84 with large criteria. The results of the study can be concluded that the STEM learning model based on design thinking is effective for improving critical thinking skills in science learning. STEM learning model based on design thinking is very good to be applied in science learning in Indonesia.

Keywords: Critical thinking skills; Design thinking; Science; STEM

Introduction

Critical thinking is the ability that students have in solving a problem systematically (Maison et al., 2022; Kanmaz, 2022; Khalaf & Alomery, 2021). Critical thinking is essential for students to understand and solve problems in life (Hamdani et al., 2022; Muzana et al., 2021). Students who have critical thinking skills are more active and easy to understand lessons (Haryati et al., 2022; Pursitasari et al., 2022; Wulandari et al., 2022; Kaowiwattanakul, 2021). In addition, critical thinking skills help students succeed in learning (Daga et al., 2022; Umam & Susandi, 2022; Amhar et al., 2022). Critical thinking skills encourage students to solve difficult problems. Adiwiguna et al. (2019) Based on the results of PISA 2018, the critical thinking skills of Indonesian students are low compared to other member countries (Arsanti & Subiantoro, 2021; Oktarina et al., 2021; Zulkifli et al., 2022; Razak et al., 2021). The teacher is still the center of learning or centered teacher (Hamengkubuwono et al., 2016), so that students are less active. Science learning concepts are still memorized, making students less active in learning (Fadhilah et al., 2022; Suhaimi et al., 2022). Use of uninteresting learning models and methods (Purwanto et al., 2022; Al-shaye, 2021).

The STEM learning model is a learning model that can improve students' critical thinking skills (Khureerung & Do, 2022; Hebebci & Usta, 2022; Topsakal et al., 2022). According to Yaki (2022) STEM is a learning model that integrates Science, Technology, Engineering, Mathematics (STEM) in the learning process. This STEM learning model is able to help students in problem solving and students' science learning outcomes (Evcim & Arslan, 2022; Wijayanto et al., 2020). Furthermore, this STEM model can improve

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students' metacognitive skills and motivation in learning science (Asigigan & Samur, 2021).

STEM model based on design thinking can improve critical thinking and problem solving skills in students (Hacioğlu & Gülhan, 2021). Febriansari et al. (2022). STEM model based on design thinking can encourage students' interest and learning outcomes in science learning. Design Thinking encourages students to create new innovations in learning (Zebdyah, 2022; Polat & Bayram, 2022). STEM model based on design thinking can help students be more creative and innovative in learning (Yalçin, 2022). Vallis et al. (2021) said the design thinking model is very effective for supporting students' 21st century learning.

Previous research by Slater et al. (2020) STEM learning model based on design thinking has a significant effect on learning outcomes and student motivation. Research by Roddy et al., (2020) The design thinking model is effective in improving students' creativity and learning outcomes. Research Herak (2021) STEM models are able to improve student learning outcomes in science learning. Therefore, so many studies have not been specific in knowing the effect of STEM models based on design thinking. Research by Coleman et al. (2020) said the design thinking model had an influence on students' 21st century thinking skills. In addition, Kazu et al. (2021) said the STEM model was effective in developing students' potential in learning science. Based on this problem, this research aims to the effectiveness of STEM learning based on Design Thinking in improving students' critical thinking skills in science learning.

Method

This research is a type of meta-analysis research. Meta-analysis is a type of research that analyzes studies that can be statistically analyzed (Yücelyiğit & Toker, 2021; Suharyat et al., 2023; Ichsan et al., 2022; Taşdemir, 2022; Ichsan, 2023). According to Hedges in Tamur et al. (2020) the steps to conduct a meta-analysis are 1) determining the inclusion criteria for each study analyzed, 2) determining the empirical data collection procedure and coding the research variables to be described, 3) determining statistical techniques to investigate the relationship between research variables and effect size. Data sources came from 100 national and international journals indexed by SINTA, Scopus and WOS published in 2017-2023. The method of selecting data sources is the PRISMA model (figure 1). The data source search process comes from the google scholar database, Sciencedirect, Eric, Wiley, Taylor of Francis, Sage, and Hindawi.

The data collection technique in the research is direct observation by browsing data sources online. The keywords used are STEM model, Design Thinking, and Science Learning. Data analysis is quantitative statistical analysis with the help of the Comprehensive meta-analysis (CMA) application. The steps of data analysis are 1) calculating the effect size value of each study and the combined effect size, 2) conducting heterogeneity tests and determining the estimation model, 3) checking publication bias, 4) calculating the p-value to test the research hypothesis (Siddaway et al., 2019; Kulik et al., 1986).

The technique used to calculate the effect size of the STEM model based on design thinking on critical thinking skills with Hedge's formula. Furthermore, the effect size value criteria can be seen in table 1.

Table 1. Effect Size (ES) Value Criteria (Suparman et al., 2021; Suharyat et al., 2022; Karaşah-Çakici et al., 2021)

Effect Size	Kriteria
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

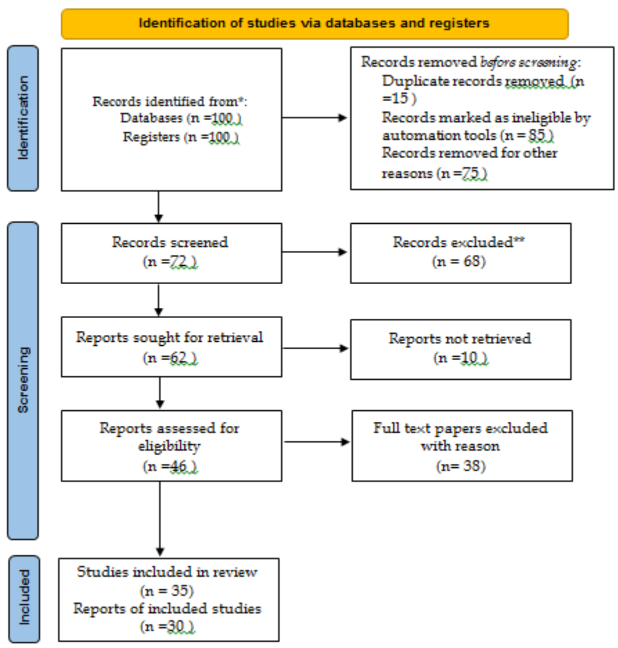

Figure 1. Flow Chart of Meta-analysis Study Selection Process

Result and Discussion

Results

From the results of the meta-analysis of 100 studies on the effectiveness of the Design Thinking-based STEM model in improving students' critical thinking skills in science learning, there were 30 studies that met the inclusion criteria. The 30 studies were 10 articles from the Google Scholar database, 3 articles from Eric, 7 articles from Sciencedirect, 2 articles from Wiley, 5 articles from Taylor of Francis, 2 articles from Hindawi, and 1 article from ProQuest. Next, determine the effect size of each study which can be seen in Table 2.

Table 2. Combined Effect Size and Confidence Interval

Study Code	Year	Effect Size	Standard Error	Criteria
J1	2022	0.92	0.43	Large
J2	2020	1.23	0.35	Large
J3	2017	0.65	0.51	Moderate
J4	2022	2.06	0.44	Very large
J5	2018	1.10	0.31	Large
J6	2021	0.59	0.44	Moderate
J7	2022	1.08	0.44	Large
J8	2022	0.43	0.35	Small
J9	2017	0.82	0.26	Large
J10	2019	-0.98	0.54	Ignored
J11	2022	1.90	0.33	Very Large
J12	2020	0.45	0.41	Small
J13	2018	0.91	0.30	Large
J14	2021	0.69	0.37	Moderate
J15	2023	0.55	0.54	Moderate
J16	2022	1.05	0.50	Large
J17	2020	0.71	0.42	Very Large
J18	2018	2.51	0.52	Very Large
J19	2022	1.70	0.39	Very Large
J20	2023	0.32	0.35	Small
J21	2017	-0.78	0.27	Ignored
J22	2022	0.82	0.37	Large
J23	2023	1.65	0.35	Very Large
J24	2019	0.20	0.61	Small
J25	2022	0.48	0.50	Moderate
J26	2021	1.34	0.45	Very Large
J27	2020	0.30	0.36	Small
J28	2022	0.88	0.52	Large
J29	2019	0.47	0.38	Small
J30	2021	1.20	0.52	Very Large
Average Effect Size		0.84		Large

Based on table 2. There are 2 out of 30 studies that have a negative effect size value which indicates the superiority of the control group. The average effect size (ES) value is 0.84 with large criteria. Furthermore, the standard error is in the range of 0.26 to 0.52, indicating that the parameters used in estimating the study are quite unstable. Thus, the effect size heterogeneity test was conducted using the Q statistic and the selection of the estimation model. Comparison of meta-analysis by estimation model can be seen in Table 3.

Table 3. Comparison of Meta-analyses by Estimation Model

Estimation model	n	Q_b	df(Q)	p-value
Fixed Effect Model	30	226.145	30	0.00
Random Effect Model	30			

Based on Table 3. Shows that the Qb value is 226.145 and the P-value <0.05. Thus, the distribution of effect size is heterogeneous. Therefore, the estimation model used is the random effect model. The next step is to analyze publication bias based on the random effect model to determine whether there is a tendency for articles to publish significant studies that cause overestimation of the true effect size. Because to find out the publication bias, the N test can be done which can be seen in Table 4.

Table 4. Rosenthal's Fail Save (FSN) Statistic

Bias Condition	
Z value for the observed study	18.13690
P value for observed study	0.00000
Alpha	0.05
Tails	2
Z value for Alpha	2.85012
Number of observed studies	30
FSN	3067

Based on Table 4 shows that the FSN value is 3067. The result of the calculation 3067 (5.30 + 10) is 19.168 > 1, so the research included in the analysis is resistant to publication bias. Therefore, there are no studies that need to be added or removed to the analysis as a result of publication bias analysis. Next, calculate the P-value to test the research hypothesis. This aims to determine whether there is an effect of the STEM model based on design thinking on students' critical thinking skills. The complete results of the overall analysis test can be seen in table 5.

Based on Table 5. Shows that the overall effect size value is 0.84 with a lower interval limit of 0.716 and an upper interval limit of 1.950. Effect size value of 0.84 is accepted with a large effect size. The standard error of 0.121 is more than the standard error of each study which indicates that the effect size value is convincing.

Table 5. Overall Analysis Results Based on Random Effect Model

Estimation model	n	Z	p	ES	SE	95 % CI	
						Lower limit	Upper Limit
Random effect model	30	8.34	0.00	0.84	0.12	0.71	1.95

The results of the Z-test to see the significance with a value of 8,340 with p = 0.000, then the STEM model based on design thinking has a significant influence on students' critical thinking skills in science learning. Next, to see the relationship between the mediator variable and is done after determining the random effect model as the model used. The identified mediator variables are sample size, research year, research source and education level. The relationship between mediator variables can be seen in table 6.

Based on table 6 Finds that all variables except the research source have no relationship with effect size (ES). Variables that have a strong relationship are sample size and education level (Qb = 0.780 > 0.05). Thus it can be concluded that the research source does not have a significant relationship with the effect size of the design thinking-based STEM model on students' critical thinking skills in science learning. So, it can be said that the STEM model based on design thinking is effective for improving students' thinking skills.

Table 6. Analysis Results Based on Mediator Variables

Mediator variabel	Group	n	Hedge's	Heterogenity		P	Conlusion
				Q_B	df(Q)		
Sample size	>26 student	30	1.720	0.780	3	0.00	Homogenity
Year	2017-2023	30	0.751	0.709	2	0.230	Heterogenity
Education level	SD	4	2.610	0.725	1	0.006	Homogenity
	SMP	6	0.230				
	SMA	12	0.710				
	PT	8	0.562				
Research Source	GS	11	1.450	10.450	3	0.130	Heterogenity
	Eric	5	0.921				
	Wiley	3	0.810				
	Taylor & Francis	4	0.652				
	ScienceDirect	4	0.710				
	Hindawi	2	0.420				
	ProQuest	1					

Disccusion

The STEM model based on design thinking has a positive influence on students' thinking skills in science learning. This can be seen from the effect size value (ES = 0.84) with large criteria. This is in line with (Abdurrahman et al., 2022) STEM model based on design thinking has a significant influence on students' critical thinking skills in science learning. STEM learning model based on design thinking is able to encourage students' creative thinking, critical thinking and problem solving skills (Sen et al., 2021; Hacioğlu & Gülhan, 2021). The STEM model helps students to be more active and creative in learning. Furthermore, the STEM model based on design thinking effectively improves students' thinking skills in learning science. This can be seen from the value ($p < 0.05$), then the STEM model has a positive impact in developing students' science learning potential.

The STEM learning model based on design thinking of each study has a significant relationship with the effect size, namely sample size and research year (Qb = 0.780 > 0.05). The design thinking-based STEM model is influenced by sample size and year of study. According to Priatna et al. (2020) said the STEM model based on design thinking was influenced by the number of students who managed to obtain satisfactory learning outcomes. The STEM model helps students and teachers to be more creative and innovative in learning science (A'yun et al., 2020; Mater et al., 2022; Linh et al., 2019). Not only that, the STEM model based on design thinking encourages students to increase their confidence and motivation to learn science (Asigigan & Samur, 2021).

The successful application of the STEM model based on design thinking in students' science learning process is determined by the ease with which students understand the subject matter. Science learning requires students to think scientifically and critically in solving a problem (Oktavia & Ridlo, 2020; Parno et al., 2019; Putra et al., 2023). These scientific thinking skills help students more easily understand science concepts and subject matter. The existence of a STEM model based on design thinking has a positive impact on making it easier to design learning that is more interesting and fun (Retnowati et al., 2020; Sutoyo et al., 2019). STEM model based on design thinking needs to be very important to be applied in science learning (Goldman et al., 2009). STEM model based on design thinking students are able to imagine effective learning in solving certain phenomena (Aguilera & Ortiz-Revilla, 2021; Chaidam & Poonputta, 2022).

The STEM model based on design thinking not only helps students but also teachers in conveying learning materials and concepts (Tu et al., 2018; Lor, 2017; Scheer et al., 2012; Ardianti et al., 2020). Science learning requires students to have critical thinking skills to make it easier to understand learning concepts (Santosa et al., 2021; Santosa & Yulianti, 2020; Fradila et al., 2021). So, the application of the right model in learning helps improve students' understanding and motivation in learning. The STEM model based on design thinking is the right learning model to improve students' critical thinking in learning (Kennedy & Odell, 2014; Chiu et al., 2021). STEM model based on design thinking increases the effectiveness of students to be more active in encouraging students' critical thinking skills.

Conclusion

Based on this research, it can be concluded that the STEM learning model based on design thinking is effective for improving critical thinking skills in science learning. STEM learning model based on design thinking is very good to be applied in science learning in Indonesia. The design thinking-based STEM model has a significant effect on students' thinking skills in science learning with an effect size value (ES = 0.84) with large criteria. This shows that the STEM model based on design thinking needs to be applied in science learning in Indonesia.

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Author Contributions
Tomi Apra Santosa; Conceptualization, methodology, data analysis, author of original design, Zulyusri: project administration and conceptualization, Review & editing Festiyed;author, supervisor , Yerimadesi; Reviewer & editing writer, Yohandri: Reviewer writer, supervisor, Abdul Razak; Reviewer & editing writer, supervisor.

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Conflicts of Interest
The authors declare no conflict of interest.

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