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Meta Analysis: The Influence of the STEM Approach in Learning Physics on Skills Students' Creative and Critical Thinking

Juliandrio[1*], Asrizal[2], Usmeldi[3]

[1,2] Department of Physics Education (Universitas Negeri Padang, Indonesia
[3] Electrical Engineering Department, FT, Universitas Negeri Padang, Indonesia

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Correspondence
Email : rioj62800@gmail.com
Phone : 085210436630

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ABSTRACT

Education in the 21st century must integrate social sciences and humanities over natural sciences and mathematics. Education can give birth to a scientific attitude, including being able to think critically, creatively, logically and adaptively. The STEM approach refers to learning mathematics, science, and technology. STEM methods can encourage students to think creatively and critically and work together with their classmates to solve modern science and technology problems. This meta-analysis uses the Cohen's d effect size calculation method. The research results obtained from this meta-analysis study include: first, the influence of the STEM approach based on the type of skill obtained. The effect size of critical thinking skills is higher with an effect size of 2.79 compared to creative thinking skills. Second, based on the learning model, the highest influence of the STEM approach was obtained on the STEM model with an effect size of 2.99. Third, Newton's law material obtained the highest effect size value of the 9 subjects, namely 6.25. Thus, the STEM approach in learning physics has an effect on improving students' creative and critical thinking skills.

INTRODUCTION

Education 4.0 is considered a solution to meet needs in the Industrial Revolution 4.0 era, where technology and humans are integrated innovatively and creatively (Putriani & Hudaidah, 2021). In order to prepare students' abilities to face the challenges of industry 4.0, it is necessary to develop skills which are now better known as 21st century skills (Wahyunita & Subroto, 2021). Meanwhile, Mulyani (2019) stated that education in the 21st century should integrate social sciences and humanities above natural sciences and mathematics. Education is expected to be able to give birth to scientific attitudes, including critical, creative, logical and adaptive thinking abilities. Meanwhile, according to Lukum (2019), education in the Industrial Revolution 4.0 era aims to develop several main competencies for the 21st century, including the ability to think and act, which includes critical thinking, creative thinking, and problem-solving abilities.

A variety of skills has become essential, especially considering the possibility of replacing humans by machines in several fields of work. However, it should be noted that the education system in Indonesia still tends to emphasize memorization, and some teachers still apply a teacher-centric learning approach. The impact of this is a decrease in students' levels of creativity and learning skills (Mutowi'ah et al., 2020). There are still many teachers who experience difficulties in developing skills in students, mainly due to the inaccuracy of the learning approaches used. As a result, the expected skills in students cannot develop. Critical, creative, collaborative thinking skills and the ability to solve problems are very important and must be possessed by students, especially considering the increasingly rapid development of technology.

As a subject that requires in-depth analysis of scientific facts and mathematical concepts, physics requires students' ability to think critically and creatively. Therefore, students need to be equipped with the ability to reason using physics concepts and principles to explain natural events and solve problems in a critical and creative way (Uli S & Rahmatsyah, 2021). According to previous research, students' ability to think critically is still relatively low, especially in physics subjects. Based on a study conducted by Endang as described in research by Wahyunita & Subroto (2021), analysis of the level of critical thinking skills at SMA 1 Woha shows that 21% of students have moderate critical thinking skills, 64% show a low level of critical thinking skills, and 15% of students have high critical thinking skills (Wahyunita & Subroto, 2021).

Apart from the low critical thinking skills in physics among students, there is another problem, namely the low level of creative thinking among students. This is caused by the lack of ability of the education system to improve students' creative skills. Studies such as those by Khoiri et al. (2023) and Batlolona and Diantoro (2023) emphasize that conventional learning methods and inadequate instructional designs hinder the development of fluency, originality, and flexibility, which are key indicators of creative thinking in physics education. Moreover, research by Kawuri et al. (2019) and findings published in *IJERE* (2020) show that integrating innovative strategies, such as Project-Based Learning (PjBL), can significantly enhance students' creative thinking skills but are not yet widely implemented in many classrooms. This is caused by the lack of ability of the education system to improve students' creative skills, as explained by Surya et al. (2018). To overcome these problems, new innovations are needed in physics learning. One solution is through the application of STEM-based learning, with the aim of helping students develop critical thinking and creative thinking skills.

There is a number of studies, including a study by Qadafi et al (2022), which shows that the STEM-based PjBL model has a positive influence on students' creative thinking abilities. This research involved 17 students as experimental class samples, and the results showed significant learning achievements. The experimental class achieved higher learning scores than the control class, with an average score of 75.33 compared to 65.29. Marwani & Sani (2020) also conducted research showing an increase in students' creative thinking skills through the integration of PjBL and STEM in learning. The posttest results from the experimental class, which involved 21 students, showed a score range between 44-75 for most students, while 14 other students scored between 76-92. Meanwhile, according to Gultom & Rahmatsyah (2021), the Inquiry Training learning model with a STEM approach also has a significant positive impact on students' creative thinking abilities. The t test on the Inquiry Training learning model with a STEM approach shows a higher value compared to conventional learning, confirming that this approach is more effective in improving students' creative thinking abilities. The STEM approach refers to learning mathematics, science, and technology. STEM methods have the potential to encourage students to develop creative and critical thinking skills, while collaborating with classmates in solving modern science and

technology problems. It is important to train students' skills so that they are able to think quickly and precisely (Santoso & Mosik, 2019).

It is believed that integrating several components in the STEM approach with other learning models can increase the impact of students' critical and creative thinking abilities. However, the results of previous research have limitations, such as: 1) research results that have not detailed the influence of various similar studies on students' critical and creative thinking skills in the STEM approach to physics learning, 2) the application of the STEM approach is only at one level of education, 3) the application STEM approach only on one type of skill, 4) limitations on the use of one integrated STEM subject, and 5) lack of relevance of references in previous meta-analysis research.

This research addresses the limitations in previous studies by conducting a meta-analysis to evaluate the impact of the STEM approach in physics learning on students' critical and creative thinking abilities. By synthesizing findings from similar research, it seeks to provide robust evidence of STEM's influence on these skills. The analysis considers various aspects, including overall effects, differences across grade levels, specific subject matter, and the integration of diverse learning models. The study's goal is to offer a comprehensive understanding of how STEM-based learning strategies can enhance cognitive abilities in physics education, supporting its broader implementation in teaching practices.

METHODS

This research employs a meta-analysis method, which is a type of study that synthesizes and reviews findings from various studies on a particular issue. The method aims to integrate data from previous studies to provide a comprehensive understanding of the research topic. In this context, the meta-analysis examines the impact of the STEM approach in physics learning on students' critical and creative thinking skills.

The articles included in this meta-analysis must meet specific criteria. First, they must feature keywords related to STEM in physics education. Second, the publications should originate from proceedings or journals published within the last six years. Third, they must include sufficient data for calculating the effect size (ES), such as the number of participants in experimental and control groups, pretest and posttest mean values, and calculated t or r values. Finally, at least 20 articles are required to conduct reliable effect size calculations.

The research variables analyzed include the influence of the STEM approach on students' critical and creative thinking abilities. These variables are explored across different dimensions, such as grade levels, subject matter, learning models, and overall effects. The focus on these variables allows the study to comprehensively assess how STEM-based learning impacts cognitive skills in physics education.

The research begins by selecting the topic and determining the scope of journals to include, covering both national and international publications. Relevant articles are collected and analyzed in-depth. The data extracted from these articles are organized into tables, a process known as coding, and then grouped based on the research objectives. The data are subsequently processed to compute effect sizes, and the final findings are compiled into a meta-analysis article.

Data analysis employs effect size formulas adapted from Becker & Park (2011), suitable for various study designs, including one-group pretest-posttest, two-group posttest only, and two-group pretest-posttest designs. Calculations involve statistical metrics such as mean values, standard deviations, and t or r values. The results are categorized into specific effect size levels to determine the magnitude of STEM's influence on students' critical and creative thinking skills.

RESULTS AND DISCUSSION

Results

The aim of this research is to assess the impact of the STEM approach in physics learning on students' creative thinking and critical thinking skills, by considering several moderating variables. This research includes three moderator variables, namely based on the type of skill, learning model, and subject matter. The research data was obtained by calculating the effect size values from the 20 articles that were reviewed. Details of the 20 articles can be found in Table 1.

Tabel 1. Article Data Research Data Source

No	Article Identity	Article Code	Author and Year of Publication
1	"The Influence of the Stem-Based Project Based Learning Model on Students' Creative Thinking Abilities in the Main Material of Static Fluids in Class Xi Smanegeri 4 Tebing Tinggi TP 2019/2020"	A1	Marwani & Sani, 2020
2	"The Influence of the STEM Integrated Project Based Learning (PjBL) Learning Model on Physics Subjects to Improve the Creative Thinking Ability of TGH Umar Kelayu High School Students for the 2021/2022 Academic Year"	A2	Moammar Qadafi et al., 2022
3	" *Implementation Of the Stem Learning To Improve The Creative Thinking Skills Of High School Students In The Newton Law Of Gravity Material*"	A3	Surya et al., 2018
4	"The Influence of Stem Models on Students' Scientific Creativity in Temperature and Heat"	A4	Doyan et al., 2023
5	"The Effect of STEM Integrated Inquiry Learning on Students' Creativity Abilities"	A5	Mutowi'ah et al., 2020
6	"Utilization of Ethno-STEM Based Teaching Materials to Increase Student Creativity in Physics Learning"	A6	Rohmantika & Kurniawan, 2021
7	"The Influence of the Inquiry Training Learning Model Using a Stem Approach on Students' Creative Thinking Abilities in Physics Learning"	A7	Gultom & Rahmatsyah, 2021

No	Article Identity	Article Code	Author and Year of Publication
8	"The Influence of the 5e Learning Cycle Learning Model Using a Stem Approach on the Creative Thinking Ability of High School Students"	A8	Uli S & Rahmatsyah, 2021
9	"*The Implementation of Integrated Project-Based Learning Science Technology Engineering Mathematics on Creative Thinking Skills and Student Cognitive Learning Outcomes in Dynamic Fluid*"	A9	Sinurat et al., 2022
10	*"Implementation of PjBL-STEM to Improve Students' Creative Thinking Skills On Static Fluid Topic"*	A10	Saefullah et al., 2021
11	*"Implementation of STEM Approach Based on Project-based Learning to Improve Creative Thinking Skills of High School Students in Physics"*	A11	Widyasmah et al., 2019
12	*"The Influence of STEM-Integrated 7E Learning Cycle on Students' Creative Thinking Skills in the Topic of Temperature and Heat"*	A12	Parno et al., 2020
13	"Application of physics learning using a STEM approach to improve students' problem-solving abilities in dynamic electricity material"	A13	Dewi et al., 2018
14	"Implementation of a STEM learning approach to improve high school students' critical thinking skills on sound wave material"	A14	Khoiriyah et al., 2018
15	"The Effectiveness of STEM (Science, Technology, Engineering and Mathematics) Based Worksheets for Training Students' Critical Thinking Skills in High School Physics Learning"	A15	Santoso & Mosik, 2019
16	"Students' Critical Thinking Ability through the STEM PjBL Model accompanied by Authentic Assessment on Static Fluid Material"	A16	Rosyidah et al., 2021
17	" *The Effect of Science, Technology, Engineering, and Mathematics (STEM) Learning on*	A17	Alatas & Yakin, 2021

No	Article Identity	Article Code	Author and Year of Publication
	Students' Problem-Solving Skills "		
18	"Stem Integrated Problem Based Learning in the Covid-19 Pandemic Era to Improve Students' Critical Thinking Skills"	A18	Putri et al., 2020
19	"*The influence of PBL-STEM on students' problem-solving skills in the topic of optical instruments*"	A19	Parno et al., 2019
20	"Effectiveness of the Blended Learning Model with a STEM Approach in Efforts to Improve Students' Critical Thinking Ability"	A20	Wahyunita & Subroto, 2021

The data presented in Table 1, comprising 20 articles coded from A1 to A20, provides a comprehensive overview of various studies related to the impact of STEM on students' critical and creative thinking skills in physics learning. These articles have been categorized into three distinct groups: skills, learning models, and subject matter. This classification aids in identifying patterns and trends across different areas of focus, allowing for a deeper understanding of how each category influences student outcomes. For instance, the "skills" category might highlight the development of cognitive abilities, while the "learning models" category could reveal the effectiveness of different pedagogical approaches in fostering critical and creative thinking. The "subject matter" category, on the other hand, offers insights into how specific physics topics are addressed within STEM frameworks. By organizing the articles in this manner, it becomes easier to evaluate the overall impact of STEM on these key skills and pinpoint areas where further research or improvement might be needed. Each article's code allows for efficient data handling and analysis, ensuring that the results of this meta-analysis are both organized and meaningful.

Discussion

The Influence of STEM in Physics Learning on Students' Overall Creative Thinking Skills and Critical Thinking Skills

The preliminary results indicate that the STEM approach in physics learning has a significant impact on students' overall critical and creative thinking abilities. To further explore these findings, the effect size results are presented in Table 2. This table provides a detailed analysis of the magnitude of the effects observed, highlighting the influence of STEM-based learning on various aspects of student performance. The data presented will help to better understand the extent to which the STEM approach enhances cognitive skills in physics education.

Table 2. Overall effect size

Component	Code	ICE	ES Mean	Category
Creative Thinking	A1	0.64	2.29	Strong effect

Skills	A2	1.02		
	A3	6.25		
	A4	1.49		
	A5	0.89		
	A6	3.66		
	A7	0.55		
	A8	0.77		
	A9	4.25		
	A10	0.89		
	A11	2.26		
	A12	4.85		
Critical Thinking Skills	A13	2.25	2.79	Strong effect
	A14	4.41		
	A15	1.28		
	A16	1.05		
	A17	4.41		
	A18	2.38		
	A19	6.24		
	A20	0.37		

From the results of the analysis in Table 2, it can be concluded that in creative thinking skills, the average effect size is 2.29 in the Strong or high effect category. Meanwhile, for critical thinking skills, the average effect size value reached 2.79 with the same category, namely Strong effect or high. Thus, it can be concluded that students' understanding of critical and creative thinking abilities in physics learning is significantly influenced by the STEM approach. According to Parno et al. (2020), STEM-integrated learning can encourage students to explore topics that spark their interests and pursue what they want to do in the future, including developing their creative ideas, especially in the fields of mathematics and science. This condition provides encouragement for improvements in learning activities, so that students can better understand physics concepts correctly, which in turn will increase students' level of critical thinking (Rosyidah et al., 2021).

The Influence of STEM in Physics Learning on Students' Creative Thinking Skills and Critical Thinking Skills in View of the Learning Model

The second finding of this research is related to the analysis of the impact of STEM in physics learning on students' creative and critical thinking abilities based on learning models. Learning models also have a significant influence on improving students' skills, especially if these models are implemented optimally and integrated with a STEM approach. In Table 3 below, the effect size values are presented which describe the class level influence of STEM based on the learning model.

The Influence of STEM in Physics Learning on Students' Overall Creative Thinking Skills and Critical Thinking Skills

Preliminary results show that the STEM approach in physics learning has an influence on students' overall critical and creative thinking skills. Details of the effect size results obtained can be found in Table 3.

Table 3. Overall *effect size*

Component	Code	ICE	ES Mean	Category
Creative Thinking Skills	A1	0.64	2.29	*Strong effect*
	A2	1.02		
	A3	6.25		
	A4	1.49		
	A5	0.89		
	A6	3.66		
	A7	0.55		
	A8	0.77		
	A9	4.25		
	A10	0.89		
	A11	2.26		
	A12	4.85		
Critical Thinking Skills	A13	2.25	2.79	*Strong effect*
	A14	4.41		
	A15	1.28		
	A16	1.05		
	A17	4.41		
	A18	2.38		
	A19	6.24		

		A20	0.37		

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Table 1. Effect size in terms of the Learning Model

Approach	Model	Article Code	*Effect size*	Average *effect size*	Category
STEM	PJBL	A1	0.64	1.62	*Strong Effect (Tall)*
		A2	1.02		
		A9	4.25		
		A10	0.89		
		A12	0.64		
		A13	2.25		
	Inquiry	A5	0.89	0.72	*Moderate Effect (Medium)*
		A7	0.55		
	STEM	A3	6.25	2.99	*Strong Effect (Tall)*
		A4	1.49		
		A6	3.66		
		A8	0.77		
		A11	2.26		

Approach	Model	Article Code	*Effect size*	Average *effect size*	Category
		A14	4.41		
		A15	1.28		
		A17	4.41		
		A18	2.38		
	PBL	A16	1.05	3.64	*Strong Effect (Tall)*
		A19	6.24		
	Blended Learning	A20	0.37	0.37	*Modest Effect*

The effect size is calculated based on 9 physics materials, as shown in Table 5. Overall, the application of STEM has a significant influence on physics materials. The highest mean effect size was found in Newton's Law material at 6.25 in the high category. Meanwhile, the lowest average effect size was in the Elasticity material at 0.55 in the medium category.

Thus, it can be concluded that the application of STEM to Newton's Law material has a greater influence on students' creative thinking abilities compared to other materials. This finding is in line with research by Surya et al. (2018) which shows that an increase in learning outcomes occurs in Newton's Law material when a STEM approach is applied when teaching the material. This can happen because STEM learning places students in situations that are able to develop their capacity to think creatively, critically and systematically through problem solving activities or assignments, so that ultimately it has an impact on achieving good learning outcomes.

Table 2. Effect Size in Terms of the Learning Model

Approach	Model	Article Code	Effect size	Average effect size	Category
STEM	PJBL	A1	0.64	1.62	Strong Effect (Tall)
		A2	1.02		
		A9	4.25		
		A10	0.89		
		A12	0.64		
		A13	2.25		
	Inquiry	A5	0.89	0.72	Moderate Effect (Medium)
		A7	0.55		
	STEM	A3	6.25	2.99	Strong Effect
		A4	1.49		

Approach	Model	Article Code	Effect size	Average effect size	Category
		A6	3.66		(Tall)
		A8	0.77		
		A11	2.26		
		A14	4.41		
		A15	1.28		
		A17	4.41		
		A18	2.38		
	PBL	A16	1.05	3.64	Strong Effect (Tall)
		A19	6.24		
	Blended Learning	A20	0.37	0.37	Modest Effect

The effect size is calculated based on 9 physics materials, as shown in Table 4. Overall, the application of STEM has a significant influence on physics materials. The highest mean effect size was found in Newton's Law material at 6.25 in the high category. Meanwhile, the lowest average effect size was in the Elasticity material at 0.55 in the medium category.

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CONCLUSION

In conclusion, the application of STEM in physics learning significantly impacts students' creative and critical thinking abilities, with varying effects across different physics topics. The highest effect size was observed in Newton's Law material, where the STEM approach yielded a large impact, as indicated by an effect size of 6.25. This suggests that students demonstrate greater improvements in their thinking abilities when engaging with this topic under STEM-based learning environments. In contrast, the Elasticity material showed a lower effect size of 0.55, indicating a medium-level impact. These results align with previous research, such as that by Surya et al. (2018), which also reported enhanced learning outcomes in Newton's Law when taught through STEM methods. This can be attributed to the problem-solving tasks and assignments inherent in STEM learning, which foster students' creative, critical, and systematic thinking, ultimately leading to improved learning outcomes.

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