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META-ANALYSIS OF THE STEM APPLICATION EFFECT ON STUDENTS' CREATIVE THINKING

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ABSTRACT

21st century learning emphasizes mastery of knowledge through a STEM approach. This study aims to evaluate research that examines the effect of STEM implementation on students' creative thinking. The moderating variables considered were educational level, learning models, and learning materials. This study employs a meta-analysis method to collect quantitative data to calculate the effect size of each relevant study. The searched national and international journals were those recognized by ISSN and DOI between 2017 and 2023. The results of the study show that the STEM approach is effective at all levels of education, the STEM approach based on learning models (PjBL, PBL, and Inquiry) effectively improves students' creative thinking, and the STEM approach based on teaching materials are effectively applied to global warming material. It can be concluded that applying STEM can improve students' creative thinking skills. Future researchers are expected to analyze certain areas of STEM implementation or look at the long-term effects of creative thinking on students.

META-ANALISIS PENGARUH PENERAPAN STEM TERHADAP BERPIKIR KREATIF SISWA

Kata Kunci:

Berpikir kreatif
Meta analyses
STEM

ABSTRAK

Pembelajaran abad 21 menekankan penguasaan pengetahuan secara melalui pendekatan STEM. Penelitian ini bertujuan mengevaluasi penelitian yang mengkaji pengaruh penerapan STEM terhadap berpikir kreatif siswa. Variabel moderator yang dipertimbangkan adalah tingkat pendidikan, model pembelajaran dan materi pembelajaran. Penelitian ini menggunakan metode meta-analisis untuk mengumpulkan data kuantitatif guna menghitung *effect size* dari masing-masing penelitian yang relevan. Pencarian jurnal nasional dan internasional yang digunakan adalah yang diakui dengan ISSN dan DOI antara tahun 2017 sampai dengan tahun 2023. Hasil penelitian diperoleh bahwa: pendekatan STEM efektif diterapkan di semua jenjang pendidikan, pendekatan STEM berdasarkan model pembelajaran (PjBL, PBL, dan Inquiry) efektif meningkatkan berpikir kreatif peserta didik, dan pendekatan STEM berdasarkan materi ajar efektif diterapkan pada materi pemanasan global. Dapat disimpulkan bahwa penerapan STEM dapat meningkatkan kemampuan berpikir kreatif peserta didik. Peneliti selanjutnya, diharapkan untuk menganalisis area tertentu dari implementasi STEM atau melihat efek jangka panjang berpikir kreatif pada siswa.

1. INTRODUCTION

UN nations decided to undertake sustainable development, often known as the Sustainable Development Goals (SDGs), to improve the world without damaging future generations [1]. The SDGs' primary objective is environmental, social, and economic development to address global warming and biodiversity loss [2]. According to the goals, 195 nations are engaged in sustainable development [1].

Construction in the 21st century aims to stay up with current knowledge and technology [3]. Technology and the application of science in education help accelerate the learning process and are widely accepted as a strategic advantage in improving the quality and standards of schools for students in the 21st century [4]. The 21st century requires students to be proficient in science and technology to become creative, innovative, intelligent, and cultured adults with a high quality of life [5]. The basic principle of 21st-century learning is student-centered, collaborative, related to real-world phenomena, and has a context related to people's lives [6].

One of the aspects emphasized in the 21st century in the field of education is students' creative thinking skills [7]. Creative thinking skills are writing that focuses on perspectives and new ways of understanding [8]. If students are creative thinkers, they will generate various ideas, and from these many ideas, they can choose the best solution to solve a problem [9]. Therefore, it can be concluded that student growth is significantly influenced by their capacity to think creatively. Learning creative thinking skills is important because it helps students develop their 21st-century talents. Students' difficulties can be solved in various ways thanks to the ability to think creatively.

The actual field situation did not match the anticipated ideal conditions. Preliminary observations reveal that students' creative thinking abilities are still lacking due to the conventional nature of their education, their inability to innovate or come up with new ideas, and their lack of practice in expressing their opinions about the content they are learning [10]. Some students still choose not to participate in practicum activities and project assignments when learning is done in these ways. These students lack the creative thinking skills needed for practical work and project assignments because they continue to rely on the smarter students in their group to take on a bigger role. Based on these problems requires a learning approach that can improve students' creative thinking skills. The learning approach is the Science, Technology, Engineering, and Mathematics (STEM) approach. This is because students who use the STEM approach are taught theory and practice through projects to hone students' creative thinking skills [11].

STEM (science, technology, engineering, and math) is the merging of the four disciplines employing a multidisciplinary approach and problem-based learning in real-world settings [12]. Utilizing the STEM approach will encourage students to use their imaginations and collaborate with their peers to find solutions to the challenges and issues presented by the most recent science and technology in the twenty-first century. [13]. The following goals are expectations for students with the STEM approach: (1) possess the knowledge, attitudes, and abilities to recognize issues in their life, describe natural occurrences, create, and come to judgments regarding STEM-related subjects based on evidence, (2) Recognize the traits of STEM fields as expressions of human knowledge, research, and design; (3) Recognize the impact that the STEM fields have on the physical, intellectual, and cultural environments; and (4) willing to use STEM concepts to conduct study on topics connected to STEM as good, empathetic, and thoughtful citizens [10].

The STEM approach aims to develop student's knowledge, conceptual understanding, and critical thinking skills [14]. In doing so, educators can participate in various STEM-related activities, encourage students to support economic growth and help them better understand the world and themselves. Learn by incorporating STEM components into a whole new educational approach. Teachers can create STEM lessons to help children become better problem solvers, planners, and decision-makers. Because it requires students to master skills in science, technology, engineering, and mathematics, this method is considered appropriate to apply. Students' talents and capacities are estimated to develop appropriately through STEM implementation.

Research related to STEM in developing creative thinking skills has been widely carried out, including STEM-based learning on creative thinking abilities [15], STEM-integrated PjBL improves creative thinking skills [16], [17], e-learning-based STEM integration improves creative thinking skills [18], and STEM-based worksheets facilitate the development of critical thinking skills [19]. From these several studies, no research has conducted a meta-analytic study examining how the application of STEM affects students' capacity to think creatively.

One of the limitations of previous studies was that they only looked at one topic area, one teaching level, and one learning model. This meta-analysis summarizes various research results quantitatively by looking for the effect size value of STEM application on students' creative thinking capacity. STEM was chosen because it can improve students' creative thinking. And to prove this, this study aims to determine how much influence STEM subjects, learning models, and educational levels have on students' creative thinking capacity.

2. METHOD

This research is a meta-analysis by presenting quantitative data in the form of effect sizes from each study. The studies used in the meta-analysis were sourced from national and international journals. The search was done through Google Scholar Journal of Physics, EURASIA Journal of Mathematics Science and Technology Education, International Journal of Curriculum and Instruction, and others using the keywords STEM, the STEM integrated learning model, and the participants' creative thinking. Title search restrictions and not included in the article section that uses these keywords. All search results were examined and assessed for use in the meta-analysis with the following criteria: (1) year of publication ranged from 2017 to 2023, (2) studies measuring the impact of STEM on students' creative thinking, and (3) learning provided sufficient data information to calculate ES (sample size, mean, standard deviation and t value). The data analysis steps are presented in Figure 1.

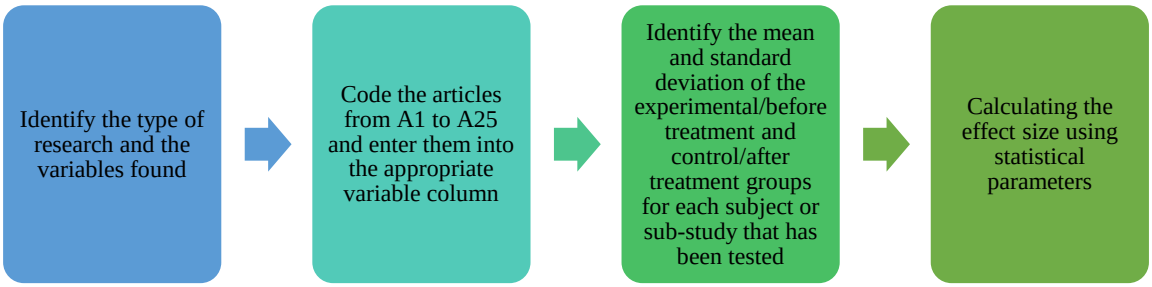

Figure 1. The Data Analysis Steps

The statistical parameter is the way to determine the effect size and effect size categories that follow the results of the acquisition of the effect size scores contained in the articles analyzed. Tables 1 and 2 categorize the following results.

Table 1. Determination of the Effect Size [20]

No	Statistics	Formula	Information
1	Average in one group	$ES = \frac{\bar{X}_{post} - \bar{X}_{pre}}{SD_{pre}}$	Fr-1
2	Average in each group (two groups posttest only)	$ES = \frac{\bar{X}_E - \bar{X}_C}{SD_C}$	Fr-2
3	Average in each group (two groups pretest and posttest)	$ES = \frac{(X_{post} - X_{pre})_E - (X_{post} - X_{pre})_C}{\frac{SD_{\text{pre}}c + SD_{\text{pre}}E + SD_{\text{post}}c}{3}}$	Fr-3
4	Chi-Square	$ES = \frac{2r}{\sqrt{1-r^2}}; \sqrt{\frac{X^2}{n}}$	Fr-4
5	$t_{observed}$	$ES = t\sqrt{\frac{1}{n_E} + \frac{1}{n_C}}$	Fr-5
6	P-value	CMA (Comprehensive Meta-Analysis Software)	Fr-6

Table 2. Effect Size Category

Effect Size (ES)	Category
0 ≤ ES ≤ 0,2	Low
0,2 ≤ ES ≤ 0,8	Medium
ES ≥ 0,8	High

3. RESULTS AND DISCUSSION

This research was conducted to review and examine several moderating factors that can help you determine the impact of STEM on students' ability to think creatively. Data were collected from journals important to this study, supporting each journal's estimated effect size. Data was collected from various sources, including Google Scholar, the Journal of Physics, the EURASIA Journal of Mathematics Science and Technology Education, and the International Journal of Curriculum and Instruction.

A total of 25 journals were selected based on certain standards. The first is a study of the impact of STEM implementation. The second is implemented in learning. The types of journals come from national and international journals. And the third effect on creative thinking skills.

The results of the effect size calculation on 25 journals are divided into three categories. First, based on education level. Furthermore, secondly, based on the learning model. Third, based on learning materials. Article codification can be seen in Table 3 below.

Table 3. Journal Coding, Sources, Effect Sizes, and Formulas Used

No	Code	Journal Source	Scale	Effect Size	Category	Formula
1	J1	Sukmawijaya et al., 2019 [21]	Indonesia	0.42	Medium	Fr-4
2	J2	Marwani & Sani, 2020) [22]	Indonesia	0.61	Medium	Fr-3
3	J3	Nur Kholifah et al., 2018 [15]	Indonesia	1.36	High	Fr-5
4	J4	Karmila & Putra, 2022 [23]	Indonesia	0.94	High	Fr-3
5	J5	Sholihah & Azizah, 2019 [24]	Indonesia	4.22	High	Fr-5

6	J6	Moammar Qadafi et al., 2022 [16]	Indonesia	1.02	High	Fr-2
7	J7	Renandika et al., 2020 [17]	Indonesia	0.90	High	Fr-5
8	J8	Riyanti, 2020 [25]	Indonesia	2.71	High	Fr-5
9	J9	Septiyani, 2022 [18]	Indonesia	4.08	High	Fr-5
10	J10	Bakırcı & Kırıcı, 2021 [26]	International	2.85	High	Fr-3
11	J11	Doyan et al., 2022 [27]	Indonesia	1.49	High	Fr-5
12	J12	Yulaikah et al., 2022 [28]	Indonesia	4.23	High	Fr-3
13	J13	Hasançebi Et Al., 2021 [29]	International	0.50	Medium	Fr-5
14	J14	Tiryaki & Adıgüzel, 2021 [30]	International	1.17	High	Fr-3
15	J15	Dogan & Kahraman, 2021 [31]	International	1.29	High	Fr-5
16	J16	Çalışıcı & Benzer, 2021[32]	International	0.74	Medium	Fr-2
17	J17	Eroglu & Bektas, 2022 [33]	International	0.82	Medium	Fr-3
18	J18	Uğraş, 2018[34]	International	0.77	Medium	Fr-1
19	J19	Yulianti et al., 2020[19]	Indonesia	6.08	High	Fr-1
20	J20	Iskandar et al., 2020 [35]	Indonesia	0.66	Medium	Fr-2
21	J21	Susilowati et al., 2020 [36]	Indonesia	1.64	High	Fr-5
22	J22	Mutowi' ah et al., 2020[37]	Indonesia	1	High	Fr-2
23	J23	Madyani et al., 2019 [38]	Indonesia	0.1	Low	Fr-5
24	J24	Jawad et al., 2017 [39]	International	1.1	High	Fr-5
25	J25	Van Broekhoven et al., 2020 [40]	International	0.64	Medium	Fr-3

Table 3 shows that the average effect size of the influence of STEM implementation on students' creative thinking skills is 1.65 in the high category. This finding implies that applying STEM can improve students' creative thinking skills.

Creative thinking skills are the principle of the teaching and learning process so that students can use their knowledge in the real world. Creative thinking skills are essential for students to apply their expertise in practical settings. It is very important to have creative thinking skills and be able to be a solution to global issues. Creative thinking is needed to create a product that can be used in everyday life [13]. The STEM approach develops students' mathematical critical thinking skills to solve problems by thinking creatively, reasoning logically and systematically, communicating, collaborating, and keeping abreast of technological developments [41].

Implementing the STEM approach provides information that the STEM approach positively increases the ability to think creatively and critically mathematically. STEM implementation can be applied to small or large classes at various levels of education. STEM is project-based and solves problems relevant to the learning model. Implementing the STEM approach in learning Mathematics is carried out with a separate approach to each STEM subject, embedded in other materials or integrated between two or more materials in STEM [41]-[44]. The following details are the results of the influence of STEM implementation on creative thinking skills based on educational level, learning model, and subject matter.

3.1 The Effect of STEM Application on Creative Thinking Skills Based on Education Level

The initial findings of this study relate to the investigation of the effect size of the relationship between STEM adoption and creative thinking ability in terms of educational level. The calculation results are shown in Table 4.

Table 4. Effect Size of The Effect of STEM Application on Creative Thinking Skills Based on Education Level

Educational level	Journal Code	Effect Size	Average Effect Size	Category
Elementary school	J7	0.90	2.60	High
	J8	2.71		
	J9	4.08		
	J12	4.23		
	J24	1.1		
Junior High School	J3	1.36	1.06	High
	J10	2.85		
	J13	0.50		
	J14	1.17		
	J15	1.29		
	J16	0.74		
	J17	0.82		
	J18	0.77		
Senior High School	J1	0.42	1.71	high
	J2	0.61		
	J4	0.94		
	J5	4.22		
	J6	1.02		
	J11	1.49		
	J19	6.08		
	J20	0.66		
	J22	1		
	J25	0.64		
College	J21	1.64	1.64	High

From the calculation of the effect size the effect of STEM implementation on students' creative thinking skills based on educational level, it is obtained effect size: 2.60 with the high effect size category for elementary school level; effect size: 1.04 with the high effect size category for the junior high school level; effect size: 1.71 with the high effect size category for the senior high school level; and effect size: 1.64 with the high category for the tertiary level.

Analysis based on the educational level found that the application of STEM was effectively used at the elementary level. However, the three levels of elementary, junior high, high school and university education have a high category effect Size. The largest effect size of the influence of STEM-based teaching materials is in elementary school. This finding shows that the application of STEM is very effectively used at all levels of education.

Generally, the STEM approach can be implemented from elementary to tertiary level [45]. It is possible because aspects of STEM implementation, such as intelligence, creativity, and design ability, do not depend on age. Therefore, it can be concluded that the STEM approach is not based on the level of education. Meanwhile, STEM can be implemented at all levels of education [41], [42]. Thus, the STEM approach is not based on the level of education.

3.2 The Effect of STEM Application on Creative Thinking Skills Based on Learning Models

Analysis of the influence of STEM based on the learning model used can be seen in Table 5, The following.

Table 5. Effect Size of The Effect of STEM Application on Creative Thinking Skills Based on The Learning Model

Learning Model	Journal Code	Effect Size	Average Effect Size	Category
PjBL	J1	0.42	1.83	High
	J6	1.02		
	J7	0.90		
	J8	2.71		
	J9	4.08		
PBL	J2	0.61	1.4S8	High
	J4	0.94		
	J10	2.85		
	J12	4.23		
	J13	0.50		
	J23	0.1		
	J24	1.1		
Inquiry	J11	1.49	1.33	High
	J14	1.17		

Table 5 displays the results of the analysis of the application of STEM to student creativity using the learning model used. The analysis of this article uses a learning model. The three learning models used in the analysis of this article are PjBL, PBL, and inquiry.

The effect of STEM application on students' creative thinking skills with the PjBL learning model has an average effect size of 1.83 in the high category. Using STEM with the PjBL learning model can help students improve their creative thinking skills. In addition, this learning model can improve skills according to the demands of the 21st century-era according to thinking [46]. The effect of STEM application on students' creative thinking skills with the PBL learning model has an average effect size of 1.48 in the high category. Tusing STEM with the PBL learning model can help students improve their creative thinking skills. The effect of STEM application on students' creative thinking skills with the inquiry learning model means the effect size is 1.33 in the high category. Applying STEM with the inquiry learning model can improve students' creative thinking skills.

The results of the analysis of the effect of STEM implementation on students' creative thinking using learning models greatly influence students' creative thinking skills. In line with research, the learning model is a strategy used by educators so that learning objectives can be realized so that students are interested in participating in the learning process properly, actively, and creatively [47]. STEM implementation has a positive effect on capacity building project-based STEM creative thinking and problem solving relevant to PjBL and PBL learning models so that STEM-PjBL or STEM-PBL integration can be used by para educators related to efforts to hone students' creative thinking abilities [41]-[44].

3.3 The Effect of STEM Application on Students' Creative Thinking Skills Based on Subject Matter

Analysis of the effect of STEM application on students' creative thinking skills based on subject matter can be seen in Table 6 below.

Table 6. The Effect Size Effect of STEM Application on Creative Thinking Skills Based on Learning Materials

Learning Materials	Journal Code	Effect Size	Average Effect Size	Category
Environmental pollution	J1	0.42	0.42	Medium
Fluid	J2	0.61	0.78	Medium
	J4	0.94		
Pressure on matter	J3	1.36	1.36	High
Global warming	J5	4.22	4.22	High
Optical tools	J6	1.02	1.16	High
	J15	1.29		
Energy sources	J8	4.08	4.08	High
Temperature and heat	J11	1.49	0.74	Medium
	J25	0.64		
	J23	0.1		
Mass and weight	J13	0.5	0.5	Medium
Effort and energy	J10	2.85	1.8	High
	J16	0.74		
Atomic structure	J17	0.82	0.82	Medium
Robotic	J14	1.29	1.29	High
Newton's laws	J20	0.66	0.66	Medium
Renewable energy	J21	1.64	1.64	High
The kinetic theory of gases	J22	1	1	High

The results of the effect size analysis of the effect of STEM implementation on students' creative thinking skills based on the subject matter showed the largest average effect size is 4.22 on global warming material. It is known that, in general, the influence of STEM implementation on learning material is high. Applying STEM to the subject matter can improve creative thinking skills very well. The more students who master the learning material, the more creative thinking skills of students will be very good. Students need to acquire higher-order thinking skills by using reasoning power to understand concepts related to the subject matter and the realities of life [48]. The teacher plays a role in communicating content to increase student knowledge and activity. STEM approach implementation in learning Mathematics is carried out in a separate approach in each STEM subject, embedded in other materials or integrated between two or more materials in STEM [41]-[44].

4. CONCLUSION

According to a review of 25 journal publications, the average size of the impact of STEM implementation on students' capacity for creative thought was 1.65 in the high category. The data implies that STEM applications can enhance pupils' capacity for creative thought. Based on the moderator variable, the following conclusions can be drawn: (1) Students' creative thinking skills are impacted by the application of STEM at all educational levels, with the elementary school level experiencing a 2.60 in the high effect size category, the junior high level experiencing a 1.04 in the high effect size category, the senior high level experiencing a 1.71 in the high effect size category, and the coeducational level experiencing a 1.64 in the high category. This finding demonstrates how effectively STEM is applied across all educational levels; (2) Based on the learning model, it can be concluded that the three PjBL, PBL, and Inquiry learning models can enhance students' creative thinking skills, with the PjBL model having an average effect size of 1.83 in the high category, the PBL model having an average effect size of 1.48 in the high category, and the Inquiry model having an average effect size of 1.33 in the high category; and (3) How STEM applications affect students' capacity for original thought The largest average effect size, according to the subject, is 4.22 in

literature about global warming. It is well-recognized that STEM implementation has a significant impact on educational materials.

Future researchers are expected to analyze particular areas of STEM implementation or look into long-term effects on students' capacity for creative thought over several years. However, this research only focused on STEM, and there are still numerous limitations regarding moderator variables.

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