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Effects of STEM Integration in Science Learning on Critical Thinking and Creative Thinking Skills: A Meta-Analysis

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ABSTRACT

Critical thinking and creative thinking skills are essential in facing the challenges of the 21st century. Integrating STEM into science learning is very important to develop students' critical thinking and creative thinking skills. Several problems were faced in its integration, including a lack of teacher understanding and skills in integrating STEM. The solution to this problem refers to meta-analysis journals, which can provide a comprehensive overview of previous research on STEM integration in science learning. This research aims to determine the effect of Stem Integration in Science Learning on Critical Thinking and Creative Thinking Skills. This type of research is meta-analysis. The re-research sample consisted of 20 journals. The data analysis technique used in this research is to calculate the effect size of each article. Integrating STEM in learning significantly affects critical and creative thinking skills at all levels of education. The highest effect size score is at the high school level, with an average effect size value for critical thinking skills of 3.08 (very high category) and creative thinking skills of 2.09 (very high category). The integration of STEM in teaching materials has a significant impact. The STEM approach gave the best results, with an effect size of 3.41 for critical thinking and 5.21 for creative thinking skills. The problem-based learning model has the highest effect size, 5.35, in critical thinking skills. Meanwhile, the project-based learning model provides a high effect size of 0.97 for creative thinking skills.

INTRODUCTION

The presence of the Industrial Revolution 4.0 has significantly impacted human life. Almost all aspects of human life today cannot be separated from the role of technology. The Industrial Revolution 4.0 also impacted the world of education in Indonesia, starting with the digitalization of the education system, which requires every element in the education sector to adapt to the changes. In Indonesia, it is necessary to create quality human resources to compete with the broader community (Nazifah et al., 2021). On this basis, 21st-century education should develop competent knowledge, skills, attitudes, and superior values

(Asrizal et al., 2021). 21st-century skills can be trained through education so that educators and students can expand their abilities with technology to improve the quality of their future careers and social life (Kristiani et al., 2017). Physics learning facilitates students to develop the 4C'S, namely critical, creative, collaboration, and communication skills (Putri et al., 2020). This is by the mandate of the 2013 curriculum, which states that the competency standards for student graduates at the High School/Vocational High School level include having the ability to think and act creatively, productively, critically, independently, collaboratively, and communicatively (Kementrian Pendidikan dan Kebudayaan, 2016).

STEM education is a global movement in educational practices integrating various integration patterns to develop quality human resources that meet the demands of 21st-century skills (Firman, 2016). The STEM approach can train students to apply the knowledge learned at school to phenomena that occur in the real world. As the abbreviation suggests, STEM (Science, Technology, Engineering, and Mathematics) is very effective when applied to learning because it combines many aspects (Sukmana, 2017). STEM integration is carried out to develop content and practices in learning and apply STEM education when facing real-life situations or problems (Kaniawati, 2016).

In order to support the success of skills in the 21st century, it is recommended to implement STEM learning, namely the integration of learning science, technology, engineering, and mathematics (Beers, 2011). According to the California Department of Education (2015), it can be concluded that STEM Education can make students active, collaborative, and skilled, and learning can be meaningful, thus broadening their horizons. The integrated application of STEM indirectly requires teachers and students to think critically and creatively in line with what was said (A. M. Santoso & Arif, 2021; Wahyunita & Subroto, 2021) that the STEM approach emphasizes learning from real-life problems to get used to finding the right solution for each problem and being able to think creatively and critically about a problem that one wants to solve.

Critical thinking is reflective thinking that focuses on deciding what to believe and what to do next (Ennies, 2011: 17). Discovering one's thoughts is one of the characteristics of critical thinking skills (S. H. Santoso & Mosik, 2019). However, students' critical thinking abilities cannot be optimally improved at school. This actual condition was discovered in several literature studies that have been carried out. First, students' critical thinking abilities are still low, as evidenced by their 70 out of 78 science scores in PISA 2018 (OECD, 2016). Innovation is carried out in the learning process to overcome low critical thinking skills using STEM (Ritonga, 2021). Integrating the four components of the STEM learning approach can produce student thinking activities that are useful in helping to bring out students' critical thinking, which is characterized by the ability to solve problems, make decisions, analyze assumptions, evaluate and carry out investigations (Davidi et al., 2021). Critical thinking skills develop in an environment that creates curiosity (Setia Permana et al., 2021).

Training students to acquire critical thinking skills can be done by any school through the learning process because critical thinking can be trained by choosing the right learning strategies and cannot be obtained in a short time without practice and habituation (Siahaan & Meilani, 2019). There are many ways that teachers can develop critical thinking skills so that students can follow learning developments according to the times by implementing one of them by choosing a learning model (Dywan & Airlanda, 2020) and learning that students can learn directly to develop critical thinking skills so that students can find answers through their learning experiences.

In science learning, students are guided by the teacher to actively find their understanding related to the learning material, which is a characteristic of learning that develops creative thinking skills (Surya & Wahyudi, 2018). In line with an opinion (Evan 1991) which states that creative thinking can help students improve the quality and effectiveness of their problem-solving abilities) and conversely, problem-solving can improve creative thinking abilities (Briggs and Davis, 2008). One way to improve students' creative thinking abilities is with a STEM approach, especially in the engineering process, which is the process of training creativity (Mawarni & Sani, 2020). Creative thinking abilities can be developed at school by providing appropriate situations, models, strategies, or media (Windasari et al., 2020). Creative thinking skills consist of 3 indicators, namely indicators of original thinking skills, flexible thinking skills, and fluent thinking skills (Surya & Wahyudi, 2018). In accordance with (Kristiani et al., 2017), indicators of creative thinking skills are as follows: a) Ability to think fluently (fluency); b) Ability to think flexibly (flexibility); c) Ability to think original (Originality); d) Ability to detail (Elaboration).

Previous research on meta-analysis in STEM integration mostly includes discussions on the scope of 4C skills and only at certain school levels. However, no meta-analysis study has discussed the effect size of critical and creative skills and involves various school levels in the scope of science learning. This approach will make it possible better to understand STEM integration's potential and overall impact. In this way, we can identify patterns, successes, and challenges that may differ between the effect sizes of school levels in the scope of science subjects so that they can be used as material in designing more effective strategies to improve students' critical and creative thinking skills in various educational contexts.

Research has previously been conducted on the influence of stems on students' critical and creative thinking skills. Considering the large number of studies regarding the influence of STEM on students' critical thinking skills and creative thinking skills, it is necessary to conduct meta-analysis research regarding the influence of STEM on students' critical thinking skills and creative thinking skills. Articles were obtained from various sources, then the effect size was calculated, and the influence on critical thinking skills and student learning outcomes from several aspects was determined. This meta-analysis research aims to: 1) determine the size of the effect of stem influence on students' critical thinking skills and creative thinking skills. In terms of school level; 2) determine the size of the effect of stem influence on students' critical thinking skills and creative thinking skills based on the type of learning support; 3) determine the size of the effect of stem influence on students' critical thinking skills and creative thinking skills based on the learning model used.

METHODS

This research uses a meta-analysis method. Meta-analysis is research carried out by summarizing, reviewing, and analyzing data from several studies that have been carried out. This meta-analysis research method examines several articles in similar national and international journals. The subjects of this research were 20 national and international journal articles published in the last seven years. The data in this research is secondary data because it was obtained from the results of research conducted previously.

In the meta-analysis method, the steps for selecting articles to be analyzed are as follows: First, determine the criteria for included articles, such as examining how STEM is used in teaching science and how it influences students' thinking abilities. Second, an article search was conducted in national journals with ISSN numbers, focusing on articles published in the last seven years to ensure the latest research results. After that, articles that fit the criteria were identified by reading the article's summary. Then, the selected articles are read in their entirety to check the extent of their relevance to the research topic. Further selection is done by thoroughly reading the selected articles considering relevance to the research topic. After selecting the appropriate articles, the data tabulation steps recommended by Agustin and Hanum (2021) were used to identify research variables, means, and standard deviations and calculate the effect size using the Glass (1981) formula if the standard deviation was known. In this journal, Table 1 presents a more detailed gain formula.

Table 1. How to determine the size of the Effect Size

Statistics	Formula
The average for one group	ES = $\frac{\bar{X}_{post} - \bar{X}_{pre}}{SD_{pre}}$
Average for each group (two groups posttest only)	ES = $\frac{\bar{X}_{eksperimen} - \bar{X}_{kontrol}}{SD_{kontrol}}$
Average for each group (two groups pre-post tests)	$ES = \frac{\left(\overline{X}_{post} - \overline{X}_{pre}\right)_{eksperimen} - \left(\overline{X}_{post} - \overline{X}_{pre}\right)_{control}}{\frac{SD_{pre\_kontrol} + SD_{pre\_eksperimen} + SD_{post\_kontrol}}{3}}$
Chi-Square	ES = $\frac{2r}{\sqrt{1-r^2}}$; r = $\sqrt{\frac{X^2}{n}}$
t count	ES = t $\sqrt{\frac{1}{n_{eksperimen}} + \frac{1}{n_{kontrol}}}$
P Value	CMA (Comerhensive Meta Analisis Sofware)

In determining the effect size, the formula Glass (1981) introduced is applied. The next step is to classify the effects based on the effect size. In this classification, effects can be classified into several different categories. An effect is categorized as negligible if the effect size value is ≤ 0.15, while a low effect occurs when the effect size value is 0.15 to 0.40. A moderate effect occurs if the effect size value is between 0.40 and 0.75, while a high effect is achieved when the effect size is 0.75 to 1.10.

Furthermore, the effect can be very high if the effect size is between 1.10 to 1.45. Finally, if the effect size value exceeds 1.45, the effect is considered a high-impact effect. Determining these effect categories is useful in providing a deeper understanding of the impacts found in this analysis.

RESULTS AND DISCUSSION

Results

From the meta-analysis study that has been carried out by determining the value of the effect size, the 20 articles that have been obtained are related to the stem and critical thinking and creative thinking skills of students up to the twentieth article (code category) given categories J1 to J20, where article J1- J20 is a national and international article. These journals are about stem education critical thinking and creative thinking skills. Article coding can be seen in Table 2 below.

Table 2. Article Coding

No	Author	Jurnal Code	EZ
1	(Hasanah et al., 2021)	J1	10,91
2	(Hacioglu & Gulhan, 2021)	J2	0,40
3	(C. D. Putri et al., 2020)	J3	3,65
4	(Dywan & Airlanda, 2020)	J4	0,79
5	(Kristiani et al., 2017)	J5	0,98

6	(Setia Permana et al., 2021)	J6	1,49
7	(Ritonga, 2021)	J7	1,41
8	(S. H. Santoso & Mosik, 2019)	J8	2,94
9	(Sabaryati & Darmayanti, 2018)	J9	2,16
10	(Iskandar et al., 2020)	J10	0,66
11	(N. Putri et al., 2019)	J11	0,66
12	(Surya & Wahyudi, 2018)	J12	6,28
13	(Destianingsih et al., 2016)	J13	4,15
14	(Heryanti, 2020)	J14	0,44
15	(Bulu & Tanggur, 2021)	J15	1,45
16	(Rosyidah et al., 2021)	J16	1,05
17	(Widana et al., 2021)	J17	0,64
18	(Mawarni & Sani, 2020)	J18	0,72
19	(A. M. Santoso & Arif, 2021)	J19	3,72
20	(Riyanti, 2020)	J20	1,31

Results Based on Educational Level

The first results of this research focus on effect size analysis to evaluate the impact of the STEM approach on students' critical thinking and creative thinking skills, considering educational level as a relevant factor. The effect size calculation data obtained is detailed in Table 3, which provides a comprehensive picture of the extent of the influence of the STEM approach in improving critical thinking and creative thinking skills. This table provides important information for understanding the differences in influence at each level of education. It strongly confirms that the STEM approach has a significant influence in improving students' critical thinking and creative thinking skills. Thus, Table 3 is the primary reference in explaining the findings of this research and provides a basis for developing an effective learning approach to developing students' critical thinking and creative thinking skills. The calculation results obtained are presented in Table 3.

Table 3. Effect Size Analysis Results Based on Education Level

	Critical Thinking			**Creative Thinking**		
School Level	**Jurnal Code**	**Effect Size**	**Effect Size Average**	**Jurnal code**	**Effect Size**	**Effect Size Average**
Elementary School	J4	0,79	1,47	J15	1,45	1,38
	J9	2,16		J20	1,31	
Junior High School	J2	0,4	0,4	J5	0,98	1,93
				J13	4,15	
				J17	0,64	
Senior High School	J1	10,91	3,08	J11	0,66	2,96
	J6	1,49		J12	6,28	
	J7	1,41		J14	4,18	
	J8	2,94		J18	0,72	
	J10	0,66				

J16	1,05

The data analyzed in Table 3 provides an overview of the influence of the STEM approach on students' critical thinking and creative thinking skills, considering educational level as the primary variable. The research results show that the influence of the STEM approach, in general, is very high in improving students' critical thinking and creative thinking skills. At the high school level, the highest effect size score was found in critical thinking skills, with a score of 3.08, followed by creative thinking skills, with a score of 2.96. At the high school level, there are six articles that discuss critical thinking skills, while for creative thinking skills, there are four articles. From this data, it can be concluded that the STEM approach significantly influences students' critical thinking and creative thinking skills, especially at the high school level. These findings provide important implications for developing STEM learning approaches at every level of education to improve students' critical thinking and creative thinking skills.

Results Based on Type of Learning Support

The second result of this research focuses on the effect size analysis related to the type of learning support in the influence of the STEM approach on students' critical thinking and creative thinking skills. The effect size calculation data is presented as an informative table and can provide a clearer understanding of the impact of using various types of learning support. This analysis provides important insights into understanding the relative effectiveness of each learning support in improving students' critical thinking and creative thinking skills through a STEM approach. These results provide a valuable basis for developing effective and appropriate learning strategies to improve students' critical thinking and creative thinking skills. The calculation results obtained are presented in the form of Table 4 below.

Table 4. Effect Size Analysis Results Based on Type of Learning Support

Type of Learning Support	Critical Thinking			Creative Thinking		
	Jurnal Code	Effect Size	Effect Size Average	Jurnal Code	Effect Size	Effect Size Average
Approach	J7	1,41	1,41	J12	6,28	5,21
	J9	2,16		J13	4,15	
	J10	0,66				
Model	J1	10,91	3,14	J5	0,98	1,56
	J2	0,4		J11	0,66	
	J3	3,65		J12	6,28	
	J4	0,79		J14	0,44	
	J6	1,49		J15	1,45	
	J16	1,05		J17	0,64	
	J19	3,72		J18	0,72	
				J20	1,31	
Teaching Materials	J1	10,91	3,4	J12	6,28	3,79
	J3	3,65		J20	1,31	

J7	1,41
J8	2,94
J16	1,05

The analysis results in Table 5 show that the average effect size for each learning support is very high. In critical thinking skills, the highest effect size score was found in teaching materials, with five articles achieving an ES score of 3.4. At the same time, the approach obtained the lowest effect size score but was still in the high category, namely 1.41. Meanwhile, STEM integration through the approach had the highest influence on creative thinking skills, with an effect size score of 5.21. Teaching materials also have a significant influence, with an effect size score of 3.79, consisting of 2 articles that emphasize worksheets as a STEM learning method to train students' creative thinking skills, in line with previous research (Pertiwi et al., 2017). Integrating STEM into science learning significantly increases critical and creative thinking skills, which can be integrated through approaches, learning models, and teaching materials. However, based on the data in Table 5, there is the lowest effect size score, namely 1.41, with a high category for integration in the form of a STEM approach to critical thinking skills.

Results Based on Type of Learning Model

The results of this research also involve the distribution of research samples based on the type of learning model applied. Details of the distribution of this research sample can be found in Table 5, which is presented as a comprehensive reference. This table provides information about the number of articles that examine each type of learning model and how it affects students' critical thinking and creative thinking skills. This data provides an overview of the extent of the influence of each learning model in improving students' critical thinking and creative thinking skills through a STEM approach. The details are presented in Table 5 below.

Table 5. Effect Size Analysis Results Based on Education Level

Model Type	Critical Thinking			Creative Thinking		
	Jurnal Code	Effect Size	Effect Size Average	Jurnal Code	Effect Size	Effect Size Average
PBL	J1	10,91	5,35	J17	0,64	0,64
	J3	3,65				
	J6	1,49				
	J16	1,05				
PJBL	J4	0,79	0,92	J5	0,98	0,97
				J14	0,44	
				J15	1,44	
				J18	0,72	
				J20	1,31	

Of the 20 journals obtained, the learning models used were problem-based and project-based learning. These results (Heryanti, 2020) state that to equip students in the era of the industrial revolution, several learning models are suitable to be applied, for example, the Project Based Learning (PjBL) learning model and STEM Project Based Learning. Based on the data in Table 5, it can be seen that the integration of STEM with critical thinking skills has the highest effect size in the problem-based learning model, which consists of 3 articles with a score of 5.35. This is in accordance with the statement (Ananda & Salamah, 2021), which states that the PBL learning model is connected to problems that occur in everyday life, so STEM is very suitable to be combined and matched to improve students' critical thinking skills. Meanwhile, the highest effect size for creative thinking skills was in the project-based learning model, with an effect size score of 0.97 in the high category of 5 articles. This aligns with research results (Rohana & Wahyudin, 2020), which state that the increase in creative thinking skills who receive project-based learning is significantly higher than that of students who receive conventional learning. However, we can conclude that stem integration using both problem based learning and project based learning models has a high influence on critical thinking skills and creative thinking skills.

Discussion

The results of this research consist of three parts, namely the influence of the STEM approach on students' critical thinking skills and creative thinking skills in terms of school level, type of learning support, and learning models described as follows.

The findings of this research consistently support theoretical studies and previous research results, which show that the STEM approach in science learning has a significant influence on improving students' critical thinking and creative thinking skills at various levels of education (Thovawira et al., 2021; Allanta et al. al., 2021). The results of the effect size analysis in Table 3 show that the influence of the STEM approach is highest at the high school level, with the highest effect size scores on critical thinking skills (3.08) and creative thinking skills (2.96). Previous research also supports these findings by showing a significant increase in high school students' critical and creative thinking skills through the STEM approach in science learning (Wahyuni, 2021; Putri et al., 2020). This result is because high school students must be more creative and critical to overcome more complicated problems in learning material compared to elementary and middle school/MTs levels (Kasuma et al., 2022; Afriyanti et al., 2018). Besides that, the high school level offers students a more complex environment for understanding physics material. Thus, using a STEM approach can provide an ideal framework to facilitate critical and creative skills and a deeper understanding of complex physics concepts (Santoso et al., 2019; Ridha et al., 2022). However, it should be noted that this research has limitations in that the sample is limited to several levels of education and certain variables. Therefore, further research involving more levels of education and a wider population will strengthen these findings and provide a more comprehensive understanding of the influence of STEM approaches in science learning at every level of education.

This research supports theoretical understanding and previous research emphasizing the importance of teaching materials and approaches in developing critical and creative thinking skills through the STEM approach in science learning (Mulyani, 2019; Oktavia, 2019; Nurhaliza et al., 2021). The effect size analysis in Table 4 shows that teaching materials have the highest effect size score on critical thinking skills (3.4). In contrast, the approach has the lowest effect size score but is still in the high category (1.41). Previous research also supports these findings by showing that the use of teaching materials and approaches that are relevant, innovative, and based on science contexts, as well as active and interactive learning approaches, are very important in improving critical and creative thinking skills in science learning through a STEM approach (Jannah & Atmojo, 2022; Muttaqin., 2023). These results align with Yuliana & Asrizal (2019) who stated that the use of teaching materials significantly affects students' skill competencies.

However, the limitation of this research is that it focuses on only a few types of learning support. Therefore, further research involving various types of learning supports in science learning will provide a more comprehensive understanding of the influence of each learning support on critical thinking and creative thinking skills.

The results of this research align with theoretical understanding and previous research which shows that the PBL (Problem Based Learning) and PJBL (Project Based Learning) learning models effectively improve students' critical and creative thinking abilities in science learning using a STEM approach. The analysis results in Table 5 show that the PBL learning model has the highest effect size score on critical thinking skills (5.35), while the PJBL learning model has the highest effect size score on creative thinking skills (0.97). Previous studies also support these findings by showing that PBL learning models that are connected to real-world problems in the context of science and project-based PJBL can effectively improve critical and creative thinking skills in science learning through a STEM approach (Nurhaliza et al., 2022; Trixie, 2023). However, the limitation of this research is that it focuses on certain types of learning models. Therefore, further research involving various types of learning models in science learning will provide a more comprehensive understanding of the influence of each learning model on critical thinking and creative thinking skills.

CONCLUSION

Based on the research results that have been obtained and the data that has been analyzed, three conclusions have been obtained. First, stem integration of critical thinking and creative thinking skills significantly impacts all aspects of education levels, with the highest effect size score at the high school level. Second, the integration of STEM critical thinking and creative thinking skills significantly impacts all types of learning support. Third, the problem-based learning model has a very high influence on critical thinking skills, with an effect size score of 5.35. These three results show that stem integration in science learning significantly influences critical and creative thinking skills at each level of education, teaching materials, and learning models. This research implies that it can provide important information and a basic idea for further research regarding integrating STEM in science learning towards critical thinking and creative thinking skills.

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