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The Effect of STEM-Based Learning Approaches on Critical Thinking Abilities and Student Learning Outcomes: Meta-Analysis

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ABSTRACT

The challenges of the 21st century require students to have 21st-century skills. To prepare students to have 21st-century skills, the learning that the teacher must carry out must also be oriented toward 21st-century learning. STEM is one of the approaches in learning science that supports 21st-century learning. Critical thinking is a person's ability to analyze problems and ideas in a more specific direction to find solutions according to reason and knowledge possessed. With hope, if students' critical thinking skills increase, student learning outcomes will also increase. Therefore, researchers are interested in conducting meta-analysis research in effect size analysis of the influence of STEM-based learning approaches on critical thinking skills and student learning outcomes. From research using the meta-analysis method through effect size analysis of 20 journals, it can be concluded that STEM-based learning significantly affects critical thinking skills and student learning outcomes.

INTRODUCTION

The 21st century requires students to be challenged to have 21st-century skills. To prepare students to have 21st-century skills, the learning that teachers must carry out must also be oriented toward 21st-century learning (Ritonga & Zulkarnain, 2021). The characteristics of 21st-century learning are 1) a student-centered learning approach; 2) students are encouraged to be able to collaborate; 3) learning material is linked to problems faced in everyday life, learning must enable students to connect with their daily lives; and 4) to prepare students to become responsible citizens, schools are expected to facilitate students to be involved in their social environment (Tanjung et al., 2022).

STEM is a curriculum that integrates four subjects (Science, Technology, Engineering, and Mathematics) in solving problems in life (Rahmaniar, 2020). In addition, STEM elaborates concepts, principles, and techniques from science, technology, and mathematics in the integration of making products, processes in student learning, and systems that are useful for life (Wilson, 2019). In line with this description, it states the aim of STEM learning so that students have critical thinking and technology skills that can be seen from reading, writing,

observing, and doing science so that when they enter society in the future, they will be able to develop the competencies they already have to apply in facing problems related to the field of STEM science (Bybee, 2013).

Knowledge is obtained through a scientific process so that students have a scientific attitude that can be used to solve problems and ability as a result or product in the form of systematic knowledge; science is understood as a whole set of ideas that refer to the same object and are logically related in everyday life (Rahardhian, 2022). Science learning does not only include concepts, principles, or theories, but there is also a 4C skills process that is taught through practicums. Teachers' expertise in choosing models, strategies, and learning methods is highly expected to be able to explore students' abilities in science learning (Syuhendri et al., 2021).

Learning outcomes are the development or progress of students after following the learning process (Fitria & Asrizal, 2021). Assessment of student learning outcomes includes aspects of attitudes, knowledge, and skills. Learning outcomes show the actual abilities of students after experiencing the learning process. With learning outcomes, someone can discover how far students can capture, understand, and own certain subjects.

Critical thinking skills are the ability to think reflectively and reason in making a person's decisions in analyzing problems and ideas in a more specific direction to find solutions according to the defense and knowledge they have. Critical thinking ability is an effort to apply rational, high-thinking activities, including analyzing, synthesizing, recognizing problems and solutions, and concluding and evaluating knowledge so that we have a high attitude and sensitivity towards ourselves and our environment (Febriawan, A., Fardha, R., & Buntu, A. et al., 2021).

STEM is a form of learning to develop technological literacy for students as an essential factor in achieving success in the 21st century to make students active, creative, effective, and fun (PAKEM). PAKEM can train students to think critically in solving problems in everyday life, be able to communicate and collaborate, and have concern for the natural environment and social sensitivity (Dywan et al., 2020). STEM learning can support educational challenges in the era of the Industrial Revolution 4.0.

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Learning innovations need to be carried out by paying attention to the suitability of models, methods, and supporting media with the characteristics of the material presented so that learning objectives can be achieved as expected. In reality, in the field, there are still many problems encountered. According to (Ariyatun and Octavianelis, 2020), it is felt that monotonous learning will further reduce students' critical thinking power because students experience boredom in the learning process. Low students' necessary thinking power impacts common student learning outcomes, especially in physics subjects. Student learning outcomes for physics subjects are still relatively below the Minimum Completeness Criteria (KKM). In general, the problems encountered in schools include: 1) students are not included in the participation of the teaching and learning process; 2) the teaching materials used are less varied and do not attract students' attention, for example, textbooks; 3) the use of learning media is not optimized according to the characteristics of the physics material so that the material presented cannot be understood by students properly; 4) student activities such as expressing opinions, answering questions and debating statements still do not appear during the learning process; 5) the teacher has not fully paid attention to students' verbal abilities so that the methods used are sometimes not by the needs of students.

Various solutions are sought by activists in the education world so that students can understand and apply learning objectives. One is STEM-based learning (Science, Technology, Engineering, and Mathematics) (Susanti, 2018). The integration of this STEM approach will help students analyze and solve problems that occur in real life so that students are ready to work (Putri et al., 2021). The STEM approach to learning can improve students' critical thinking skills, and students can relate these problems using science, technology, engineering, and mathematics into real contexts that enable students to compete in 21st-century life (Terbimbing et al., 2020). There are three objectives of this research. First, to see how much influence STEM-based learning has in education level on critical thinking skills and student learning outcomes, and second, in terms of the type of teaching materials/media. And third in terms of learning models.

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 journal articles by calculating the effect size. Effect size is defined as the magnitude of the effect between two or more variables expressed in ES. The themes studied were taken from national and international journals. The subjects of this research were 20 STEM-based learning articles consisting of 16 national journal articles and four international journal articles published from 2015 to 2021.

The criteria for analyzed journal articles are as follows: First, they reviewed STEM-based learning and looked at its influence on critical thinking skills and student learning outcomes. Second, this article comes from national and international journals that have ISSN. Third, the article was published in the last seven years. The steps for data analysis are (1) identifying the type of research and research variables that have been found, entered in the appropriate variable column, (2) identifying the mean and standard deviation of data from the experimental group/before treatment and control class/after treatment to for each subject/sub research that has been tested, (3) calculate the effect size using the following statistical parameters:

Calculating a variable's effect size can be done in several ways. If the statistical data consists of the average for one group, the following equation (1) is used.

$$ES = \frac{\bar{X}_{post} - \bar{X}_{pre}}{SD_{pre}} \quad (1)$$

If statistical data consists of the average for each group (with groups posttest only), then the following equation (2) can be used.

$$ES = \frac{\bar{X}_E - \bar{X}_C}{SD_C} \quad (2)$$

If the statistical data has an average in each group (with the two groups pre-posttest strategy), then the following equation (3) is used.

$$ES = \frac{(\overline{X}_{post} - \bar{X}_{pre})E - (\overline{X}_{post} - \bar{X}_{pre})C}{\frac{SD_{pre\ C} + SD_{pre\ E} + SD_{post\ C}}{3}} \quad (3)$$

If the effect size value has been calculated based on the appropriate formula, then the effect size is entered into the relevant category, as in Table 1.

Table 1. Effect Size Criteria

Effect Size	Category

ES ≤ 0,15	Very low
0,15 < ES ≤ 0,40	Low
0,40 < ES ≤ 0,75	Currently
0,75 < ES ≤ 1,10	Tall
ES > 1,10	Very high

(Source: Amelia. R, Asrizal, Festiyed, 2021)

RESULTS AND DISCUSSION

Results

This research was conducted to see the effect of STEM-based learning on students' critical thinking skills and learning outcomes by reviewing and analyzing several moderator variables. Data was obtained from journals relevant to this research and support the calculation of the effect size for each journal. Researchers collect data from various sources such as Google Scholar and Crossref.

A total of 20 journals were selected based on specific criteria. The first is research on STEM-based learning (science, physics, chemistry, and biology), the second is learning based on educational level, and the third is its influence on students' critical thinking skills and learning outcomes. The types of journals come from accredited national and international journals with ISSN. The results of calculating the effect size of the 20 journals above are classified into three parts based on education level, based on the type of teaching material, and the learning model. Article codification can be seen in Table 2.

Table 2. Code, Journal Source, Effect Size, Categories Used

Journal Code	Journal Source	ES	Category
	Students' critical thinking abilities		
J1	(Dywan, Airlanda, 2020)	0.64	Medium
J2	(Tureni, Febriawan, & Farda, 2021)	1.68	High
J3	(Mustofa, Arif, & Sholihah, 2021)	1.59	High
J4	(Wastiti, Sulur, 2019)	3.07	High
J5	(Ariyatun, Dissa, 2020)	1.37	High
J6	(Wahyuni, Dewi, Lestari 2022)	2.09	High
J7	(Rahardhian, 2022)	2.62	High
J8	(Ritonga, Zulkarnain, 2021)	2.48	High
J9	(Muyassarah, Ratu, & Erfan, 2019)	3.28	High
J10	(Almahida, Gamaliel, 2020)	1.34	High
	Student learning outcomes		
J11	(Ilmi, Ratnawati, Subhan, 2021)	0.20	Low
J12	(Marpaung, Dariati, Santoso, 2022)	0.34	Low
J13	(Wibawa, Saritasa, Suarni, 2022)	0.8	Medium
J14	(Aryanta, 2020)	1.30	High
J15	(Musdalifa, Syuhendri, Pasaribu, 2021)	1.22	High
J16	(Rikardus herak, 2021)	2.40	High
J17	(Putri, Lesmono, Nurani, 2020)	2.0	High
J18	(Susanti, 2018)	0.25	Low
J19	(Fitria, Asrizal, 2021)	1.99	High
J20	(Eliyawati, Yayan, & AS Ramdani, 2020)	1.09	High

Based on the data in Table 2, we can see a description of each journal that has been analyzed. This table shows the effect size of each article regarding the influence of STEM-based learning on critical thinking skills and student learning outcomes. In general, the average effect size results for the impact of STEM-based learning on critical thinking skills and student learning outcomes are in the high category, namely 2.16 for the average effect size on critical thinking skills and 1.16 for the average effect size on student learning outcomes.

Table 3. Effect Size of STEM-based learning based on education level

Level Education	Journal Code	Critical thinking skills			Learning outcomes			
		ES	Mean ES	Category	Code Journal	ES	Mean ES	Category
SD	J1 J10	0.64 1.34	0.99	Medium	J11 J13	0.20 0.8	0.12	Low
SMP/Mts	J3 J6 J7	1.59 2.09 2.62	2.10	High	J16	2.4	2.4	High
SMA/SMK	J2 J4 J5 J8 J9	1.68 3.07 1.37 2.48 3.28	2.37	High	J12 J14 J15 J17 J18 J19 J20	0.34 1.3 1.22 2.0 0.25 1.99 1.09	1.17	High

Table 3 shows the influence of STEM-based learning on critical thinking skills and student learning outcomes. This research was mostly carried out at the high school/vocational school level, and the results obtained were indeed higher than those from the elementary and middle school levels. The effect size analysis of the influence of STEM-based learning on critical thinking skills has the highest effect at the high school level, with an average effect size of 2.37. Meanwhile, the effect size analysis of the impact of STEM-based learning on learning outcomes has the highest effect at the junior high school level, with an average effect size of 2.4. It is just that the influence of STEM-based learning on critical thinking skills at the elementary school level is still low; this might be a further consideration for conducting relevant research. So, it can be concluded that STEM-based learning has more influence at the high school/vocational school education level and is in line with research (Herak, 2021), which shows that teaching materials for physics learning are effectively used at the high school level.

The Effect of STEM-Based Learning on Critical Thinking Ability and Student Learning Outcomes Based on Teaching Materials

The second result in this research is related to the effect size analysis of the influence of STEM-based learning on critical thinking skills and student learning outcomes in terms of teaching materials/media. The calculations obtained are presented in Table 4.

Table 4. Effect Size of STEM-Based Learning Based on Teaching Materials

Types of materials/media teaching	Teaching Code	*Effect Size*		Means ES	Category
		Critical Thinking	Learning outcomes		
LKS/LKPD	J12		0.34	0.34	Medium

	J3	1.59		1.44	High
	J4	1.3			
Module	J16		2.4	2.4	High
	J1	0.64		0.64	Medium
	J15		1.22		
	J18		0.25		
Materials/ media	J17		2.0	2.43	High
teach electronics	J20		1.99		
	J14		1.3		
Book	J5	1.37		2.22	High
Print teaching materials	J4	3.07			

Analysis of the influence of STEM-based learning on critical thinking skills and student learning outcomes regarding teaching materials/media showed that electronic teaching materials/media had the highest average effect size, namely 2.43. Of the 20 journals analyzed, eight articles did not include the teaching materials/media used in learning. Therefore, classically electronic teaching materials/media significantly influence STEM-based learning on critical thinking skills and student learning outcomes.

The Influence of STEM-Based Learning on Critical Thinking Abilities and Student Learning Outcomes Based on Learning Models

The third result in this research is related to the effect size analysis of the influence of STEM-based learning on critical thinking skills and student learning outcomes in terms of the learning model, and then the effect size of critical thinking and learning outcomes and the average effect size. The calculations obtained are presented in Table 5.

Table 5. Effect Size of STEM-Based Learning Based on Learning Model

Learning model	Journal Code	Effect Size		Means ES	Category
		Critical thinking	Learning outcomes		
	J3	1.59		2.49	High
	J11	0.20			
	J14	1.3			
	J15	1.22			
	J19	1.99			
PjBL					
	J12	3.28			
	J16	0.99			
	J18		0.25		
PBL	J17		2.0	2.43	High
	J20		1.99		
Guided inquiry	J5	1.37		1.37	High

Analysis of the effect of STEM-based learning on critical thinking skills and student learning outcomes in terms of learning models integrated with STEM shows that the PjBL (project-based learning) learning model has the highest average effect size of 2.49. In addition, the PjBL learning

model is most widely used in STEM-based learning. Even though nine journals do not include models in their research, this does not change the position of the PjBL learning model, which is the most influential research. Therefore, the PjBL learning model significantly influences STEM-based learning on critical thinking skills and student learning outcomes (Muyassarah et al., 2019).

DISCUSSION

The results of the analysis state that the PjBL learning model has the strongest influence in STEM-based learning on critical thinking skills and student learning outcomes, in line with the research results (Wibawa, I., P., G. S. et al., 2020). The research results reveal that STEM-integrated PjBL can increase students' interest in learning, make learning more meaningful, help students solve real-life problems, and support future careers (Wahyuni et al., 2022). In addition, STEM in PjBL provides challenges and motivates students because it trains students to think critically, analyze, and improve higher-order thinking skills (Marpaung et al., 2022). Through STEM learning, students can think critically about technology, which can be seen from reading, writing, observing, and doing science so that they can be used as provisions for living in society and solving problems faced in everyday life related to the STEM field of science (Ilmi et al., 2021).

CONCLUSION

Based on the data analyzed in this research, it can be stated that STEM-based learning significantly influences critical thinking abilities and student learning outcomes in terms of 3 aspects: level of education, type of teaching materials/media, and learning models used. At the educational level, STEM-based learning has a higher impact at the junior high school/MTS level compared to the elementary, high school/vocational school levels. Regarding the type of teaching materials/media, the use of electronic teaching materials/media has a stronger influence than the use of LKPD/LKS, modules, books, or printed teaching materials. Regarding the type of learning model, STEM-based learning using the PjBL learning model has a higher impact than the PBL or guided inquiry learning models. Therefore, from this research, which uses a meta-analysis method through effect size analysis from 20 journals, it can be concluded that STEM-based learning significantly influences critical thinking skills and student learning outcomes.

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