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Meta-Analysis of Students' Cognitive Abilities and Critical Thinking Skills Through the STEM Integrated Learning Model

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Abstract

The purpose of this study was to see how the STEM integrated learning model influences the cognitive abilities and critical thinking skills of students in physics subjects. This type of research is meta-analysis research. The sample used was 18 articles that met the criteria. There are two dependent variables used in this study, namely cognitive abilities and critical thinking skills. While the moderator variable is based on classes, lessons and learning models. The data collection technique used is through coding, with data analysis techniques using effect size techniques. Based on the data that has been analyzed in this study, it can be concluded that: 1) The STEM integrated learning model is proven to have an impact on students' cognitive abilities, especially if the learning model is integrated with the PBL learning model, and can have an influence on students' critical thinking skills, especially if integrated with the PJBL learning model, 2) The STEM integrated learning model is proven to have an impact on students' cognitive abilities, especially in class XII, and can have an influence on students' critical thinking skills, especially in class IX, 3) The STEM integrated learning model is proven to have an impact on students' cognitive abilities, especially on thermodynamic material, and can have an influence on students' critical thinking skills, especially on dynamic electricity material.

Keywords*: Cognitive abilities, Critical thinking, Learning models, STEM*

1. Introduction

According to the National Education System Law number 20 of 2003, education is a program in which the learning process requires conscious and planned efforts so that students can play an active role in developing their potential to have spiritual strength, self-control, personality, intelligence, noble character, and skills needed by oneself, society, nation and state (Wijayanto et al., 2020). Education is not only emphasized on mastering material but also on mastering skills (Simbolon & Sahyar, 2015). For this reason, it is necessary for students and teachers to play a collaborative role in order to create an interactive and innovative learning atmosphere.

Learning in schools greatly influences the quality of learning to create quality human resources. In (Cahyaningsih & Roektiningroem, 2018) it is stated that there are two indicators that describe the achievement of the quality of human resources, including cognitive learning outcomes and critical thinking. To achieve the desired goals, a good learning method is needed, so that the teaching and learning process becomes effective. One possibility that can be implemented is choosing the right learning model. With the competencies possessed by teachers, it is hoped that they will be able to choose appropriate learning models to achieve predetermined learning goals so that the learning outcomes obtained are maximum (Simbolon & Sahyar, 2015).

However, based on observations from several articles, the reality in the field shows that ongoing learning activities still use conventional models, the models used are less innovative and varied (Cahyaningsih & Roektiningroem, 2018; Dywan & Airlanda, 2020; Wahyuni, 2021a; Yanni, 2018) . The lack of variety in the learning models used will make students less interested in studying physics, causing students to be passive in the learning process and as a result there will be a decrease in students' activity processes and/or thinking activities, especially in high-level thinking abilities, such as critical thinking abilities (Yatmi et al., 2019). Research (Cahyaningsih &

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Roektiningroem, 2018) also revealed that things like this will have an impact on students' critical thinking skills which in turn will affect their cognitive abilities.

In response to this, many researchers are trying to apply various learning models to improve students' cognitive abilities and critical thinking skills. One way is to use a learning model that is integrated with a STEM approach. The STEM approach can motivate students to be more active in discussions because to solve problems systematically, skills are needed to apply scientific principles, so that it can encourage students to excel and get good grades (Wahyuni, 2021b). In research conducted by (Cahyaningsih & Roektiningroem, 2018) science learning using the PBL learning model integrated with the STEM approach had an influence on students' critical thinking skills and cognitive learning outcomes with an effect size in the medium category.

Furthermore, research by (Faizah et al., n.d.) showed that by using the PBL learning model, obtained from 28 students, 21 students had an influence on cognitive learning outcomes in the medium category, and as many as 7 students had an influence on learning outcomes in the high category. This is because students already understand the concepts of the material being taught, thus making students actively involved directly in preparing project designs in solving problems using physics concepts.

For critical thinking skills, research results (C. D. Putri et al., 2020) show that the STEM-integrated PBL learning model has a high influence on students' critical thinking skills in online learning. Meanwhile, research results (Ariyatun & Octavianelis, 2020) show that the influence of the STEM integrated PBL learning model on critical thinking skills is in the medium category. The PJBL-STEM learning model by (Maryam & Darmono, 2022) has a high influence on students' critical thinking skills.

On the basis of these different research results, it is necessary to carry out further analysis to draw conclusions regarding the influence of the STEM integrated learning model on students' cognitive abilities and critical thinking skills. For this reason, meta-analysis research was carried out, where the formulation of the research problem was how the use of the STEM integrated learning model affected students' cognitive abilities and critical thinking skills in terms of class level, learning model and subject matter. The aim of this research is threefold, namely to see how much influence the use of the STEM integrated learning model has on students' cognitive abilities and critical thinking skills in terms of class, grade level, learning model and subject matter.

2. Method

This research uses a meta-analysis method. The meta-analysis method is research carried out by summarizing, reviewing and analyzing data from several studies with similar problems (Sanuaka et al., 2022). The data used is secondary data, where secondary data is data obtained from the results of previous research without having to carry out research in the field. Data collection for the research was carried out by searching a number of articles via Google Scholar, with the keywords "STEM integrated learning model", "cognitive abilities and "critical thinking skills". The results of the article search found 18 articles that met the established criteria.

There are two dependent variables used in this research, namely cognitive abilities and critical thinking skills. Meanwhile, the moderator variables are based on class, subject matter and learning model. The steps taken in this research are (1) choosing the topic to be researched, (2) collecting article data that matches the criteria for the chosen topic, (3) looking for the effect size value of each article, (4) determining the category effect size of each article, (5) grouping articles according to predetermined moderator variables, (6) drawing conclusions from the results of data processing.

The data collection technique used is through coding, with data analysis techniques using effect size techniques. The effect size calculation can be seen in **Table 1**. After calculating the effect size using the appropriate formula, the effect size is then categorized using the criteria listed in **Table 2.**

Table 1. How to calculate effect size

NO	Statistics	Formula
1	Average in a group	$ES = \frac{\bar{X}_{post} - \bar{X}_{pre}}{SD_{pre}}$
2	Average in each group	$ES = \frac{\bar{X}_{eksperimen} - \bar{X}_{kontrol}}{SD_{kontrol}}$
3	Average in each group	$\frac{(\bar{X}_{post} - \bar{X}_{pre})_e - (\bar{X}_{post} - \bar{X}_{pre})_k}{\frac{SD_{Pre\ k} + SD_{pre\ e} + SD_{post\ k}}{3}}$
4	T count	$ES = \sqrt{\frac{1}{n_{eksperimen}} + \frac{1}{n_{kontrol}}}$
5	Chi-Square	$ES = \frac{2r}{\sqrt{1 - r^2}}; r = \sqrt{\frac{X^2}{n}}$
6	P	CMA (Comerhensive Meta Analisis Software)

(Cohen, 1988)

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Table 2. Effect Size Category

NO	ES	Category
1	ES ≤ 0,15	Very Low
2	0,15 < ES ≤ 0,40	Low
3	0,40 < ES ≤ 0,75	Currently
4	0,75 < ES ≤ 1,10	High
5	ES > 1,10	Very High

(Becker, 2011)

3. Results and Discussion

The aim of this research is to see the influence of the STEM integrated learning model on students' cognitive abilities and critical thinking skills by reviewing and analyzing several moderator variables. Data was obtained from articles that are relevant to this research and the effect size can be calculated for each article.

A total of 18 articles were selected because they met certain criteria, namely research on the STEM integrated learning model implemented in physics learning. The results of the effect size calculations from the 18 articles are then grouped into three parts, namely based on lesson, based on class, and based on learning model. The codes for each article can be seen in **Table 3.**

Table 3. General Article Distribution

Journal Code	Grade	Learning Model	Material	ES	Category
A1	XI	Guided Inquiry	Temperature and Heat	2,2	Very high
A2	X	PBL	Work and Energy	0,11	Very low
A3	X	STEM	Work and Energy	3,27	Very high
A4	XI	PBL	Thermodynamics	5,64	Very high
A5	VIII	PBL	Thermodynamics	0,75	Currently
A6	XI	STEM	Sound Waves	0,99	High
A7	X	Guided Inquiry	Momentum and Impulse	1,42	Very high
B8	XI	PBL	Temperature and Heat	0,002	Very low
B9	XI	STEM	Sound Waves	1,71	Very high
B10	IX	PjBL	Dynamic electricity	3,03	Very high
B11	X	PBL	Work and Energy	1,08	High
B12	X	PBL	Newton's Laws	1,49	Very high
B13	XI	Blended Learning	Dynamic Fluid	0,06	Very low
B14	XI	PjBL	Static Fluid	0,99	High
B15	XI	7E Learning Cycle	Temperature and Heat	1,33	Very high
B16	V	Guided Inquiry	Light	0,01	Very low
B17	XI	Blended Learning	Temperature and Heat	1,27	Very high
B18	X	PBL	Temperature and Heat	3,17	Very high

Based on table 3, you can see the description of the articles and the effect size obtained for each article regarding the Cognitive Abilities and Critical Thinking Skills of Students Through the STEM Integrated Learning Model. The table explains the journal code, class level, learning model, material, effect size of each article and the categories obtained from each article that has been analyzed. Cognitive abilities articles were coded A and critical thinking skills articles were coded B.

From **Table 3** it is known that the influence of the STEM integrated learning model has effects in different categories, ranging from very low to very high. In general, in articles on students' cognitive abilities given code A, the highest effect size value is in article code A4, namely the PBL learning model in class XI thermodynamics material with an effect size value of 5.64 and the category is very high. Meanwhile, the lowest effect size is in article code A2, namely the PBL learning model for class XI business and energy material with an effect size value of 0.11 in the very low category. This is because students still find it difficult to relate learning material to science, technology, engineering and mathematics (Y. E. E. Putri et al., 2020).

Meanwhile, in the critical thinking skills article which was given code B, the largest effect size value was in article code B18, namely the PBL learning model for class X temperature and heat material with a value of 3.17 and the category was very high. while the lowest effect size is in article code B8 with the PBL model for temperature and heat material with a value of 0.02 and the category is very low. The cause is that there are obstacles in implementing the STEM approach, including poor preparation and inspiration of students. Students are more accustomed to learning using conventional methods, so students do not have the readiness, motivation and inspiration to learn in applying the STEM approach. Furthermore, Lack of connection with individual learners in a wide variety of ways. Lack of student connection to things that can enhance learning in STEM fields. Then Lack of support from the school system. Lack of support from the school system. Lastly, Poormethod of assessment (Afifah et al., 2019). So that the analysis results are more significant, grouping is carried out based on predetermined moderator variables.

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***a.* Effect of STEM Integrated Learning Models based on Learning Models**

The first results in this research were analyzed based on the effect size of the influence of the STEM integrated learning model on students' cognitive abilities and critical thinking skills as viewed from the learning model. The calculation results can be seen in **Table 4 and 5.**

Table 4. Distribution of Articles Based on Learning Models on Cognitive Abilities

Learning Model	Cognitive Abilities			
	Journal Code	ES	Average ES	Category
Guided Inquiry	A1	2,2	1,81	Very High
	A7	1,42		
PBL	A2	0,11	2,16	Very High
	A4	5,64		
	A5	0,75		
STEM	A3	3,27	2,13	Very High
	A6	0,99		

Based on **Table 4**, it can be seen how the STEM integrated learning model influences students' cognitive abilities. In the guided inquiry learning model, the effect size value was 1.81 in the very high category. For the PBL learning model, a score of 2.16 was obtained in the very high category and the STEM learning model obtained a score of 2.13 in the very high category. These three learning models have a very high category for students' cognitive abilities. However, the summary effect size of the three learning models shows that the PBL learning model has a more significant impact on students' cognitive abilities. This means that students' cognitive abilities will have more impact if they use the STEM integrated PBL learning model.

This is in accordance with the statement (Faisal et al., 2022; Wijayanto et al., 2020) which states that PBL-STEM makes the student learning atmosphere in class more interesting because it involves students' creativity directly in working together and finding solutions to the problems given in learning, so that students are more interested in learning and more easily understand the lesson material provided.

Research by (Kulsum et al., 2020) states that all learning achievements facilitated by science-based subjects can be realized through the implementation of the PBL-STEM learning process, because STEM with the Problem Based Learning model can encourage understanding of the relationship between principles, concepts and students' skills, so that they can increase curiosity and stimulate students' creative imagination and can develop students' abilities in applying their knowledge, so that students can improve their learning outcomes.

Table 5. Distribution of Articles Based on Learning Models on Critical Thinking Skills

Learning Model	Critical Thinking Skills			
	Journal Code	ES	Average ES	Category
PBL	B8	0,002	1,43	Very High
	B11	1,08		
	B12	1,49		
	B18	3,17		
PJBL	B10	3,03	2,01	Very High
	B14	0,99		
STEM	B9	1,71	1,71	Very High
Blended Learning	B13	0,06	0,66	Currently
	B17	1,27		
7E Learning Cycle	B15	1,33	1,33	Very High
Guided Inquiry	B16	0,01	0,01	Very Low

Based on **Table 5**, it can be seen how the STEM integrated learning model influences students' critical thinking skills. In the PBL learning model, the effect size value was 1.43 in the very high category. For the PJBL learning model, a score of 2.01 was obtained in the very high category, the blended learning learning model had an effect size value of 0.66 in the medium category, the STEM learning model obtained an effect size value of 1.71 in the very high category, the 7E Learning Cycle learning model obtained The effect size value was 1.33 in the very high category, and the guided inquiry learning model obtained an effect size value of 0.01 in the very low category. So it can be concluded that the STEM integrated learning model that has the highest influence is the PJBL learning model because it obtains the highest effect size value.

This is in line with research conducted by (Afifah et al., 2019) which states that the use of the Project Based Learning (PjBL) model combined with a STEM approach can improve students' critical thinking skills, because the activities carried out in learning have great opportunities to train students' critical thinking skills through characteristics in their approach that are more oriented towards active student involvement, which is able to stimulate students to think critically.

Apart from that, (Bulu & Tanggur, 2021) also stated that the STEM-based PjBL Model is collaborative in nature which encourages students to design project plans, discuss planned projects in groups, and carry out projects, thus forcing students to sharpen their critical thinking, fostering their creativity in designing and producing projects, fostering a collaborative attitude within the group, collaborating ideas for project

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implementation, and encouraging learning motivation due to a positive learning environment.

b. Effect of STEM Integrated Learning Model based on Grade Level

The second result in this research was analyzed based on the effect size of the influence of the STEM integrated learning model on students' cognitive abilities and critical thinking skills as viewed from grade level. The calculation results can be seen in table 6 and table 7.

Table 6. Distribution of Articles Based on Grade Level on Cognitive Abilities

Grade	Cognitive Skills			
	Journal Code	ES	Average ES	Kategori
VIII	A5	0,75	0,75	Medium
	A2	0,11		
X	A3	3,27	2,29	Very High
	A7	1,42		
	A1	2,2		
XII	A4	5,64	2,94	Very High
	A6	0,99		

Based on **Table 6**, it can be seen how the STEM integrated learning model influences students' cognitive abilities in terms of class level. In class VIII, an effect size value of 0.75 was obtained in the medium category, in class X, an effect size of 2.29 was obtained in the very high category, and in class So it can be concluded that the STEM integrated learning model on cognitive abilities has the highest influence in class XII. The effect size in class XII shows that the STEM integrated learning model provides a very good effect. This shows that the higher the class level, the more influence the STEM integrated learning model has on cognitive abilities.

Table 7. Distribution of Articles Based on Grade Level on Critical Thinking Skills

Grade Level	Critical Thinking Skills			
	Journal Code	ES	Average ES	Category
V	B16	0,01	0,01	Very Low
IX	B10	3,03	3,03	Very High
	B11	1,08		
X	B12	1,49	1,91	Very High
	B18	3,17		
	B8	0,002		
	B9	1,71		
	B13	0,06		
XI	B14	0,99	0,89	High
	B15	1,33		
	B17	1,27		

Based on **Table 7**, it can be seen how the STEM integrated learning model influences students' critical thinking skills in terms of class level. In class, an effect size value of 0.01 was obtained in the low dsngst category, in class IX an effect size value was obtained of 3.03 in the very high category, in class X an effect size value of 1.91 was obtained in the very high category, and in class XI obtained an effect size value of 0.89 in the high category. So it can be concluded that the STEM integrated learning model has a better impact if implemented in class IX.

c. Effect of the STEM Integrated Learning Model based on Materials

The third result in this research was analyzed based on the effect size of the influence of the STEM integrated learning model on students' cognitive abilities and critical thinking skills in terms of the learning material. The calculation results can be seen in **Table 8 and Table 9.**

Table 8. Distribution of Articles Based on Material on Cognitive Abilities

Material	Cognitive Abilities			
	Journal Code	ES	Average ES	Category
Work and Energy	A2	0,11	1,69	Very High
	A3	3,27		
Thermodynamics	A4	5,64	3,19	Very High
	A5	0,75		
Temperature and Heat	A1	2,2	2,2	Very High
Sound waves	A6	0,99	0,99	High
Momentum and impulse	A7	1,42	1,42	Very High

Based on **Table 8**, it can be seen how the STEM integrated learning model influences students' cognitive abilities based on learning materials. In the work and energy material the effect size value obtained is 1.69 in the very high category, in the thermodynamic material the effect size value is 3.19 in the very high category, in the temperature and heat material the effect size obtained is 2.2 in the very high category. high, sound wave material with an effect size of 0.99 in the high category and momentum and impulse material obtained an effect size value of 1.42 in the very high category. So, it can be concluded that the STEM integrated learning model has a better influence on cognitive abilities when combined with thermodynamics material.

This is in line with research conducted by (Bukifan et al., 2020) that there is a significant difference in cognitive abilities with cognitive levels from C2 to C6 after being given ADI learning for STEM education with an effect size value of 2.39 indicating that ADI learning for STEM education has a strong influence on students' cognitive abilities. Furthermore, research by

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(Faisal et al., 2022) states that the application of the Project Based Learning model with a STEM approach to the Laws of Thermodynamics material can improve student learning outcomes because students can understand the concept of the material provided and students can be actively involved directly in preparing project design in problem solving using physics concepts.

Table 9. Distribution of Articles Based on Material on Critical Thinking Skills

Material	Critical Thinking Skills			
	Journal Code	ES	Average ES	Category
Temperature and Heat	B8	0,002	1,44	Very High
	B15	1,33		
	B17	1,27		
	B18	3,17		
Sound Waves	B9	1,71	1,71	Very High
Dynamic electricity	B10	3,03	3,03	Very High
Work and Energy	B11	1,08	1,08	High
Newton's Laws	B12	1,49	1,49	Very High
Dynamic Fluid	B13	0,06	0,06	Very Low
Static Fluid	B14	0,99	0,99	High
Light	B16	0,01	0,01	Very Low

Based on **Table 9**, it can be seen the influence of the STEM integrated learning model on students' critical thinking skills when viewed from the learning material. In temperature and heat material the effect size value obtained is 1.44 in the very high category, in sound wave material the effect size value obtained is 1.71 in the very high category, in dynamic electrical material the effect size value is 3.03 in the very high category. high, work and energy material, the effect size value is 1.08 with the high category, Newton's law material obtained an effect size value of 1.49 with a very high category, dynamic fluid material obtained an effect size of 0.06 with a very low category, static fluid obtained a size an effect of 0.99 in the very high category and light material obtained an effect size of 0.01 in the very low category. So we can conclude that the STEM integrated learning model for critical thinking skills when viewed from the learning material is better if used on dynamic electrical material because it gets the largest effect size value, namely 3.03. This is supported by research conducted by (Rahardhian, 2022) that there is an influence of implementing the STEM-based PjBL model on students' critical thinking abilities as shown by obtaining post-test results that are better than pre-test results.

4. Conclusion

Based on the data that has been analyzed in this research, it can be concluded that: 1) The STEM integrated learning model is proven to have an influence on students' cognitive abilities, especially if the learning model is integrated with the PBL learning model, and can have an influence on students' critical thinking skills, especially if integrated with the PJBL learning model, 2) The STEM integrated learning model is proven to have an influence on students' cognitive abilities, especially in class XII, and can have an influence on students' critical thinking skills, especially in class IX, 3) The STEM integrated learning model is proven to have an influence on students' cognitive abilities, especially in thermodynamics material, and can have an influence on students' critical thinking skills, especially in dynamic electricity material.

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