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The Effect of STEM Integrated Science Learning on Scientific Literacy and Critical Thinking Skills of Students: A Meta-Analysis

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Abstract: The development of 21st century education requires students to have 21st century skills, one of which is critical thinking skills and scientific literacy as well as technological developments that are developing rapidly so that STEM-based teaching materials are very popular for use. The purpose of this study was to determine the effect of similar research using STEM integrated science learning on students' scientific literacy abilities and critical thinking skills. The method used in this investigation is meta-analysis. The research results obtained are First, the effect of several similar studies on STEM-integrated science learning shows that STEM-integrated science learning has a very high influence on students' scientific literacy abilities and students' critical thinking skills. Second, the effect of several similar studies based on educational level shows that high school level has a higher influence on students' scientific literacy skills and students' critical thinking skills. Third, the influence of several similar studies based on the learning model used shows that the PBL model has a higher influence on students' scientific literacy skills and students' critical thinking abilities. Fourth, the effect of several similar studies based on learning subjects shows that biology subjects have a higher influence than physics and science subjects.

Keywords: Critical Thinking; Scientific Literacy; STEM

Introduction

In the 21st century, science and technology have developed very rapidly. We as humans live in this century so that we can participate and follow progress. New innovations have been introduced across a number of disciplines to better prepare humanity for the challenges that lie ahead. The same thing applies to education, where teachers must prepare students to face life in the 21st century. One of them is by equipping students with the skills they need. The Ministry of Education and Culture states that the 21st century learning paradigm emphasizes students' abilities to gather information from various sources, collaborate in problem solving, and think critically (Wijaya et al., 2016). In addition, 21st century learning is student-centered, collaborative, connected to the real world, and has context and purpose (Asrizal et al., 2018).

In the 21st century, scientific literacy is the main competency that humans must possess. Adult humans must have scientific literacy as a skill necessary to advance their personal, professional, social, cultural, or political activities (National Research Council, 1996). Scientific literacy concerns the ability to organize, analyze, interpret quantitative data and scientific information (Gormall et al., 2012). It can be concluded that in order to properly organize, analyze, and understand the acquired knowledge, individuals must have the main skill, namely scientific literacy. In addition to scientific literacy, critical thinking skills are also needed in the 21st century. The ability to think critically is an ability that puts forward reasoning and processing the information obtained so that its validity can be accounted for (Hidayati et al., 2019).

One of the six elements of the Pancasila student profile specified in Minister of Education and Culture

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Regulation No. 22 of 2020, namely the ability to think critically is also known as the ability to reason critically in the independent curriculum concept (Rahardhian, 2022). Reading and writing are just two examples of literacy skills. However, in the independent curriculum students must master six basic literacy skills. Scientific literacy is one of them.

In fact, the literacy of Indonesian students is in the low category, which ranks 60th out of 65 countries, this was explained in a PISA study conducted in 2016. (Wahyu et al., 2020). Students who lack scientific literacy and critical thinking skills during the learning process sometimes have difficulty understanding important concepts. Finally bring a significant influence on student learning outcomes.

The same thing was found by the previous researcher, Hashanah (2021), in his research showing that students have low critical thinking skills. Low critical thinking skills are caused because in the learning process, students only focus on material by memorizing, students do not do practical work to the fullest, so students are not given the opportunity to analyze a problem, identify, conclude, or present new ideas or actions. On a problem. Implementation of learning only obtains information without going through observation and discussion activities, and teachers still often use the lecture method in learning, according to several other studies, which also found that these factors contribute to the low ability to think critically in discussion (Ramli et al., 2020; Fadlina et al., 2021; Nurazmi & Hartono, 2021). This of course causes students to have difficulty solving the problems they face critically. Students lack the confidence to communicate thoughts or opinions because they are not taught how to identify problems. Previous researchers have shown that STEM integrated learning is the best approach to overcome this problem and improve student learning outcomes.

STEM principles which stand for science, technology, engineering, and mathematics are combined to produce complete knowledge and abilities that can enhance the education and learning process (Ercan et al., 2016; Guzey et al., 2016; Griese et al., 2015). STEM is a learning approach that can improve abilities and create quality human resources according to the skills requirements of the 21st century (Rustman et al., 2016). The STEM approach has advantages, one of which is being able to answer questions about the best method for learning science and produce individuals who are ready with the work orientation needed in the employment field because STEM is already used to solve problems (Santoso et al., 2021).

The results of previous studies have limitations. These limitations include, 1) the results obtained do not explain the effect of several studies similar to integrated science learning on students' scientific literacy skills and critical thinking skills, 2) only implementing STEM integrated science learning at one educational level, 3) only applying one model STEM-integrated learning, 4) only uses one STEM-integrated subject. Based on these limitations, this study wanted to integrate all existing similar studies to determine the effect of several similar studies of STEM-integrated science learning on students' scientific literacy and critical thinking skills using the meta-analysis method.

A quantitative study known as meta-analysis uses statistical analysis techniques to obtain research information based on data from previous research processes (Sukamto, 1998). Meta-analysis is done to research other people's studies and get the right data. In statistical analysis, results can be combined in meaningful ways. The results of each study were converted into an effect size to allow comparisons between them.

Meta-analytic research was chosen as a research method for several reasons, namely 1) many articles discussed the effect of STEM-integrated science learning on students' scientific literacy skills and critical thinking skills, 2) meta-analytic research did not depend on school conditions thereby reducing the risk of research delays, 3) there is no research on the effect of STEM-integrated science learning on students' scientific literacy skills and critical thinking skills, 4) it is not yet known the effect of a number of similar studies using STEM-integrated science learning on students' scientific literacy abilities and critical thinking skills that have a significant effect based on education level, subject and the learning model used.

Integrating STEM in science learning can improve scientific literacy skills and students' critical thinking skills. In this regard, many previous researchers have proven it, but gave different conclusions. Based on this, it is important to conduct meta-analysis research on the influence of STEM-integrated science learning on students' scientific literacy abilities and critical thinking skills. The purpose of this study was to see how much influence STEM integrated science learning had in terms of educational level, learning model and subjects on students' scientific literacy abilities and critical thinking skills.

Method

Meta-analysis is the method used in this investigation. Meta-analysis is the process of conducting research by compiling, examining, and interpreting data from numerous prior studies. The information gathered is secondary information, which was gleaned from articles published in national and international journals that summarized the findings of earlier studies. The

following measures were done in this study: Create a study question first, focusing on how STEM integration affects students' scientific literacy and critical thinking capabilities. Next, choose 20 articles that were both published in national and international journals between 2018 and 2022. Journal articles that evaluate the impact of STEM-integrated science learning must meet certain criteria in order to be considered for analysis. Additionally, the moderator variable in this study must be connected to scientific literacy and critical thinking abilities, and the journal articles used must be accredited as shown by the ISSN and DOI. The criteria for this study are shown in Table 1 for more information. Third, the researcher used a formula shown in Table 2 to determine the effect size of each journal article. Fourth, the moderator variable was used to average the effect size values that were acquired. Fifth, based on the effect size category in Table 3, the average effect size value is classified. Sixth, interpreting the research findings and developing conclusions. The following is the flow of this research which will be explained in Figure 1.

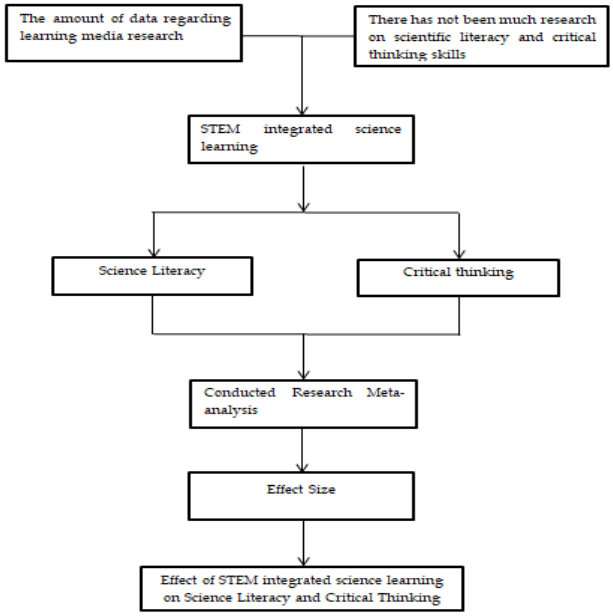

Figure 1. Research Flow

Table 1. Journal Criteria

Title	Journal state
Rahardhian, (2022)	National
Santoso et al., (2019)	National
Alifiyah et al., (2020)	National
Asigigan & Samur, (2021)	International
Widayoko et al., (2018)	National
Santoso & Arif, (2021)	National
Dywan & Airlanda, (2020)	National
Wahyu et al., (2020)	International
Dewi et al., (2021)	National
Ramli & Yohandri, (2020)	National
Fadlina et al., (2021)	National
Mater et al., (2020)	International
Fadhilah et al., (2022)	National
Retnowati et al., (2020)	International
Mustikasari et al., (2020)	International
Nurazmi& Bancong, (2021)	National
Siregar et al., (2019)	International
Noviana Putri et al., (2020)	International
Indrasari et al., (2020)	International
Qurrota & Rusilowati, (2020)	National

Table 2. How to determine the magnitude of the *Effect Size*

Data Statistik	Equation	Formula
The average in one group	$ES = \frac{\bar{x}_{post} - \bar{x}_{pre}}{SD_{pre}}$	Fr - 1
The average in each group	$ES = \frac{\bar{x}_{ek} - \bar{x}_{k}}{s_k}$	Fr - 2
The average in each group	$ES = \frac{(\bar{x}_{post} - \bar{x}_{pre})_E - (\bar{x}_{post} - \bar{x}_{pre})_C}{\frac{SD_{preC} + SD_{preE} + SD_{postC}}{3}}$	Fr - 3
t count	$ES = t\sqrt{\frac{1}{n_E} + \frac{1}{n_C}}$	Fr - 4

The effect size is then classified using the criteria shown in Table 3 after being calculated using the appropriate formula.

Table 3. Criteria *effect size (ES)*

ES	Category
ES ≤ 0.15	Very Low
0.15 < ES ≤ 0.40	Low
0.40 < ES ≤ 0.7	Currently
0.75 < ES ≤ 1.10	High
ES ≥ 1.10	Very High

Result and Discussion

Analysis of how similar research affected students' critical-thinking and scientific literacy abilities

Table 4 details how several related research were calculated to have an impact on students' scientific literacy and critical thinking abilities. Table 4's information allows you to see a description of each analyzed article. The effect sizes of each paper about how STEM-integrated science education affects students' scientific literacy and critical thinking abilities are shown in the table. The average effect sizes on students' scientific literacy and critical thinking abilities as a result of STEM-integrated science education are often very high.

Table 4. The effect of similar research on students' scientific literacy and critical thinking skills

Article Source	Article Code	Formula	Effect Size	Mean
Rahardhian, (2022)	AR1	Fr-1	2.6	1.91
Santoso et al., (2019)	AR2	Fr-1	2.2	Very High
Asigigan & Samur, (2021)	AR4	Fr-1	0.42	
Santoso & Arif, (2021)	AR6	Fr-3	3.6	
Dywan & Airlanda, (2020)	AR7	Fr-4	1.6	
Dewi et al., (2021)	AR9	Fr-4	1.65	
Ramli & Yohandri, (2020)	AR10	Fr-1	0.6	
Fadlina et al., (2021)	AR11	Fr-1	3.5	
Mater et al., (2020)	AR12	Fr-3	1.75	
Fadhilah et al., (2022)	AR13	Fr-4	3.4	
Retnowati et al., (2020)	AR14	Fr-2	1.44	
Nurazmi & Bancong, (2021)	AR16	Fr-2	3.8	
Siregar et al., (2019)	AR17	Fr-4	0.72	
Indrasari et al., (2020)	AR19	Fr-4	0.89	
Qurrota & Rusilowati, (2020)	AR20	Fr-4	0.45	
Alifiyah et al., (2020)	AR3	Fr-2	2.32	2.39
Widayoko et al., (2018)	AR5	Fr-1	3.17	Very High
Wahyu et al., (2020)	AR8	Fr-2	3.44	
Mustikasari et al., (2020)	AR15	Fr-1	1.3	
Noviana Putri et al., (2020)	AR18	Fr-1	1.7	

Analysis of the effect of similar research based on educational level

The second finding in this study relates to the extent of the impact of STEM-integrated science learning on students' critical thinking and scientific literacy skills relative to their educational background. The results of the calculations are shown in Table 5.

Table 5. The Effect of STEM Integrated Science Learning on Science Literacy and Critical Thinking Skills by Education Level

Category	Journal Code	ES	Mean	Category
Primary School	AR4	0.42	1.55	Very High
	AR7	1.6		
	AR8	3.44		
	AR17	0.72		
Junior High School	AR1	2.6	1.71	Very High
	AR6	3.6		
	AR14	1.44		
	AR15	1.3		
	AR19	0.89		

Category	Journal Code	ES	Mean	Category
Senior High School	AR20	0.45	2.4	Very High
	AR2	2.2		
	AR3	2.32		
	AR5	3.17		
	AR9	1.65		
	AR10	0.6		
	AR11	3.5		
	AR16	3.8		
	AR18	1.7		

On the basis of Table 5, it is possible to demonstrate how STEM-integrated science instruction affects students' scientific literacy and critical thinking skills. STEM-integrated science education has been shown to have a positive impact on students' critical thinking and scientific literacy skills at the elementary, middle, and high school levels, with an average score in the very high category. The reason why high school is more advanced than elementary and junior high school is because more research is done there. According to the results of the effect size calculations, senior high school students' scientific literacy and critical thinking skills are impacted by STEM-integrated science instruction. This is consistent with research that demonstrates the effectiveness of STEM-integrated learning in physics instruction at the high school level.

Analysis of the effect of similar research based on the learning model used

In terms of learning models, the third finding in this study relates to the effect size analysis of the impact of STEM-integrated science learning on students' scientific literacy skills and critical thinking abilities. The results of the calculations are shown in Table 6.

Table 6. The Effect of STEM Integrated Science Learning on Science Literacy and Critical Thinking Skills based on the Learning Model Used

Category	Journal Code	ES	Mean	Category
PJBL	AR1	2.6	1.90	Very High
	AR3	2.32		
	AR7	1.6		
	AR15	1.3		
	AR18	1.7		
PBL	AR13	3.4	2.55	Very High
	AR16	3.8		
	AR20	0.45		
ETC	AR6	3.6	3.55	Very High
	AR11	3.5		

In an analysis of the impact of STEM-integrated science learning on students' critical thinking abilities and scientific literacy skills, it was discovered that the PJBL (Project Based Learning) learning model has a very high effect size. The PJBL learning model is the most popular in STEM-based science learning. Rahardian (2022) claims that the PJBL learning paradigm can boost students' critical thinking abilities, creativity, and motivation to collaborate in groups. This can be demonstrated by the findings of the calculation of the PJBL learning model's effect size, which fall into the very high category. This indicates that the STEM-integrated PJBL model has an impact on students' scientific literacy skills and critical thinking abilities. The PBL approach is likewise rated in the very high range, indicating that it has a favorable impact on students' capacities for scientific literacy and critical thinking. According to research by (Fadhilah et al., 2022), integrating the PBL model with STEM can enhance students' critical thinking abilities as well as their scientific literacy abilities and character. The effect size calculation results for an inquiry-based learning model and a discovery learning model are in the very high category, indicating that these two models have a positive impact on students' literacy and critical thinking abilities.

Analysis of the effect of similar research based on Subjects

The study's fourth finding relates to an analysis of the impact of STEM-integrated science instruction on students' scientific literacy skills and critical thinking abilities with regard to subject matter learning. The results of the calculations are shown in Table 7.

Table 7: The Effect of STEM Integrated Science Learning on Scientific Literacy and Critical Thinking Skills by Subject

Category	Journal Code	ES	Mean	Category
PHYSICS	AR 1	2.6	2.34	Very High
	AR 2	2.2		
	AR 3	2.32		
	AR 5	3.17		
	AR 10	0.6		
	AR 16	3.8		
	AR 18	1.7		
Natural Science	AR 6	3.6	2.13	Very High
	AR 7	1.6		
	AR 8	3.44		
	AR 15	1.3		
	AR 17	0.72		
BIOLOGY	AR 11	3.5	3.45	Very High
	AR 13	3.4		

The average effect size calculation for each subject has a positive influence on scientific literacy capabilities and critical thinking abilities, which is in the very high category, according to analysis of the effect of STEM-integrated science learning on scientific literacy skills and students' critical thinking skills. Physics is a subject that is frequently used in STEM integration and has a significant impact on students' scientific literacy and critical thinking abilities.

Conclusion

There are four conclusions that can be derived from this research based on the analysis' findings. First, the results of multiple related research on STEM-integrated science learning indicate that this type of learning has a significant impact on students' capacity for scientific literacy and their capacity for critical thought. Second, the results of various related research based on educational level indicate that high school level has a greater impact on students' capacities for scientific literacy and critical thought. Third, the PBL model has a greater impact on students' scientific literacy capacities and students' critical thinking abilities, according to the results of various related research based on the learning model employed. Fourth, the results of numerous related studies based on academic subjects indicate that biology has a greater influence than physics and science. This study can serve as a guide for creating STEM-integrated science instruction across a range of educational levels, instructional models, and subject areas.

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Conflicts of Interest
The authors declare no conflict of interest.

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