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The Effect of STEM Approach on Students' Critical Thinking Skills

Media Roza[1,*], Minda Azhar[2], Festiyed[2], Prima Aswirna[3], Rika Purnama Sari[4]
[1,3]Tadris Physics Study Program, Universitas Islam Negeri Imam Bonjol Padang, Jl. M. Yunus Lubuk Lintah Padang, 25153, Sumatera Barat, Indonesia
[2]FMIPA, Universitas Negeri Padang, Jalan Prof. Dr. Hamka, Air Tawar Padang, Sumatera Barat, 25132, Sumatera Barat, Indonesia
[4]SMP Islam Terpadu JUARA, Jl Abdul Hamid Hakim, Komp. STAI Imam Bonjol, Kota Padang Panjang, Sumatera Barat, Indonesia
*Corresponding Author. E-mail address: mediaroza@uinib.ac.id

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ABSTRACT

The influence of the STEM approach has been widely studied. However, a summary of how much influence STEM has on critical thinking skills from these various studies has not been done well. This article examines the impact of the STEM approach on students' capacity for critical thought when studying physics and science. This type of research is quantitative research with meta-analysis methods. Articles from recent four-year publications in national and international journals serve as data sources. Only 16 articles met the criteria for further analysis. This study's method of data analysis involved calculating the effect size to provide a summary effect size. There are four moderator variables analyzed: learning models, teaching materials, subject matter, and education level. Based on the study's findings, it can be said that the STEM approach to fostering students' critical thinking abilities has the largest impact size when used in motion systems courses at the high school level, using media schoology and worksheets for the students. The STEM approach is proven to have a high summary effect size on students' critical thinking skills, with a score of 1.37 (high category).

1. INTRODUCTION

The era of globalization requires qualified, competitive, and adaptive Indonesian human resources in all situations. The best way to be able to compete in a global world is to equip human resources with various 21st-century skills through education. The Partnership for 21st Century Skills states that the competencies needed in the industrial revolution era 4.0 are "The 4 Cs," namely communication, collaboration, critical thinking, and creativity (Lufri et al., 2022; Roza, et al., 2022; Moser, 2017; Mumford & McIntosh, 2017).

Everyone is racing to find innovation by strengthening the quality of education. Competence and high competitiveness in humans will be tips for winning competence in the 4.0 revolution era. Competence in the 21st century era is crucial for students to have in implementing learning to guide them to have creative, innovative abilities, think critically in solving problems, and be communicative (Ananda et al., 2021). As a result, it is reasonable to predict that education in the 4.0 or 21st century age will continue to be important and will serve as a complement to the phenomena of digital penetration in daily life.

Education 4.0 prepares students to directly address digital concerns, where the essence of this phenomenon is the mindset, creativity, and great curiosity of students, so that in the future they can produce graduates who have good quality and skills. Therefore, learning activities in education 4.0 units should be carried out systematically, actively, inspiringly, and fun, and should provide motivation for students to actively participate in providing ideas and creativity and be independent in expressing their talents and interests. To support this, learning must meet at least four principles: student-centeredness, collaboration, integration with real life, and having clear context and goals (Asrizal et al., 2018).

In the fourth industrial revolution, critical thinking abilities are the main emphasis of educational activities (Linh et al., 2019). Critical thinking skills can be formed from several habits, including understanding concepts, classifying, analyzing, collecting, and evaluating information obtained through scientific methods (Siegel, 2013). Whereas the scientific method itself entails observation, formulation of issues, formulation of theories, gathering of information, testing of theories, and formulation of conclusions. If students have fulfilled some of these skill criteria, it can be said that they already have the capacity for critical thought in their learning. In addition, this critical thinking focuses on reflective thinking (Hand et al., 2018), and leads to the analysis of arguments or certain opinions, admit mistakes and bias, and provide conclusions based on the evidence and considerations obtained (Arends & Kilcher, 2010) .

Learning activities should help students enhance their critical thinking abilities by relating what they are learning to real-world context issues. One of the main objectives of education is to help pupils become more adept at critical thinking (Tee et al., 2018), where the development of critical thinking abilities emphasizes the learning process through analysis in order to foster the capacity for clear, logical thought (Higgins, 2014). Of course, to do this effectively and help students develop their critical thinking abilities, educators must play a crucial part in learning activities. However, this ability cannot be maximized in schools. 16 years old, Indonesia is in a position of low science ability level. Besides that, based on PISA (Program for Student Assessment) data for a period of 15 years, Indonesia is still in a low science ability position (OECD, 2016). The results of the study show a similar thing: the average score for critical thinking abilities among students for each indicator is on average below 50% (Hidayanti et al., 2016).

Other evidence that shows the lack of capacity for critical thought in students is shown in several studies, including research in Thailand, where it was found that students' critical thinking skills were still low due to teaching methods that were less varied and the school system (Boa, 2018). In addition, the low critical thinking ability of students is caused by learning that is still teacher-centered, where this condition causes students' critical thinking skills to not be improved (Hairida, 2016). If this condition occurs continuously, students' critical thinking skills cannot develop optimally as expected, and will have an impact on student learning outcomes. Among the subjects that can develop critical thinking skills are science and physics learning.

Studying physics and science is expected to run according to the demands of the current curriculum. However, the fact is that science learning in the field is not as expected, especially with the spread of COVID-19, which requires educators to keep up with changes in technology, learning theory, and changes in educational needs and students (Jowsey et al., 2020). Likewise, physics instruction attempts to educate students to deal with changing situations in life and in a world that is experiencing change (Alistiana, L., Aswirna, P., & Y, A., 2020). Physics learning is usually less desirable, considered difficult, and feared by many students. This condition originates from learning experiences where students find physics learning that only addresses conceptual issues and solves questions with high difficulty through mathematical formulas. Additionally, because of the class's inadequate learning environment, students only participate passively in the learning process (Ananda et al., 2021).

Knowledge and technology that are developing rapidly in the current era are expected to be important factors in supporting the quality of students. Educational challenges also increase with the development of technology (Putriyani & Irawan, 2021). So, based on this, an approach is needed to strengthen pupils' capacity for critical thought, one of which is using the STEM (Science, Technology, Engineering, and Mathematics) learning approach (Onsee & Nuangchalerm, 2019).

STEM approach stands for science, technology, engineering, and mathematics (Estapa & Tank, 2017). The STEM approach is considered to be able to encourage students to develop 21st-century skills (Techakosit & Nilsook, 2018). The STEM learning approach is effectively used in learning because students do not always feel suitable for all conventional learning conditions and environments (Jowsey et al., 2020). If STEM is connected to the environment, it will be able to grow, and students will learn about real-world situations that they encounter every day (Sagala et al., nd). STEM applications can help students plan, construct, and utilize technology well, improving affective, psychomotor, and cognitive skills. According to certain research findings, STEM can enhance conceptual understanding and critical thinking abilities (Fan & Yu, 2015; Lufri, L., & Asrizal, 2023).

The results of searching for national and international journal articles using Harzing's Publish or Perish application obtained 400 articles related to the effect of the STEM approach on students' capacity for critical thought in learning science and physics. However, from the results of the investigation based on the criteria for the articles needed in this study, 16 research articles were found with various conclusions expressed in relation to the use of learning models, teaching materials or learning media used, materials used, and educational level.

Based on the problems described above, it can be seen that the impact of using the STEM approach has been extensively researched. However, a summary of how much influence STEM has on critical thinking skills from these various studies has not been done well. Therefore, a meta-analysis study is needed to see how much the impact of the STEM approach on students' capacity for critical thoughts. This article aims to analyze the effect of the STEM approach on students' critical thinking skills in learning science and physics based on the four moderator variables; learning models, teaching materials or learning media used, materials used, and educational level.

2. MATERIALS AND METHODS

This kind of research uses a meta-analysis methodology and is quantitative. The meta-analysis aims to determine the relevance of the research topic after the treatment. This study analyzes publications in international and national journals from 2018 to 2021. Literature search using keywords through the Publish or Perish application. After searching, there were more than 400 articles related to the influence of the STEM approach to learning science and physics in junior and senior high schools on students' critical thinking skills. However, after being evaluated, only 16 papers met the requirements for further investigation.

This research was obtained by collecting various research journals from various accurate sources, such as Google Scholar, Scopus, the Directory of Open Access Journals, and others in international, national, and other similar sources, which were then arranged and selected according to the specified criteria. Descriptive statistical analysis techniques used to examine the data acquired for this investigation were the effect size of each article and the summary effect size of the influence of the STEM approach on students' critical thinking abilities. The effect sizes were calculated using the Cohen formula based on the mean, standard deviation, calculated t-value, and sample size (Retnawati, et al., 2018). How to calculate the effect size can be seen in Table 1.

Table 1. The formulas used to calculate the effect size

Statistical Data	Formula
If known, only the mean value of the control group, the mean value of the experimental group, the standard deviation of the control group, and the standard deviation of the experimental group.	$ES(d) = \frac{\bar{X}post_E - \bar{X}post_C}{SD_{within}}$ Where : $SD_{within} = \sqrt{\frac{(n_E-1)SDpost_E^2 + (n_C-1)SDpost_C^2}{n_E+n_C-2}}$
For the two groups of independent samples, the mean value and posttest-pretest posttest-pretest standard deviation of the experimental class were identified. and known, the mean value of the posttest-pretest and the standard deviation of the posttest-pretest control group.	$ES(d)= \frac{(\bar{X}post_E - \bar{X}post_E)-(\bar{X}post_C - \bar{X}pre_E)}{SD_{within}}$ Where : $SD_{within}= \sqrt{\frac{(n_E-1)SDpre_E^2+(n_C-1)SDpre_C^2+(n_E-1)SDpost_E^2+(n_C-1)}{2(n_E+n_E-2)}}$

Statistical Data	Formula
For a comparison test of two independent samples, if the number of samples in the control group, the number of samples in the experimental group, and the value of tcount are known	$ES\ (d) = \frac{\bar{X}post_E - \bar{X}post_C}{SD_{within}}$ If the number the number of the control group is the same as the experimental group then: $SD_{within} = \frac{\bar{X}post_E - \bar{X}post_C}{t_h\sqrt{\frac{2}{n}}}$ If the number of the control group is different from the number of the experimental group, then: $SD_{within} = \frac{\bar{X}post_E - \bar{X}post_C}{t_h X \sqrt{\frac{1}{n_E}+\frac{1}{n_C}}}$
For the pretest-posttest contrast design, and if it is known, the average value of posttestE and pretestE	$ES\ (d) = \bar{X}post_E - \bar{X}pre_E$ where: $SD_{within} = \sqrt{\frac{(n_1-1)xS_1^2+(n_2-1)x\,S_2^2}{n_1+n_2-2}}$
To find the value of variance d	$V_d = \frac{n_E + n_C}{n_E x n_C} + \frac{d^2}{2(n_E + n_C)}$ $Sed = \sqrt{V_d}$
To change d to Hedge's g, use the correction factor (J). The (J)	$J = 1 - \frac{3}{4df-1}$ after: $g = J \times d$ $Vg = J^2 \times V_d$ $Seg = \sqrt{Vg}$

The criteria for determining the effect size are categorized using the reference from Glass can be seen at Table 2.

Table 2. Criteria effects size

No	Effects sizes	Category
1	ES 0.15	Negligible
2	0.15 < ES < 0.40	Low
3	0.40 < ES < 0.75	Medium
4	0.75 < ES < 1.10	High
5	ES > 1.10	Very high

(Modified from Glass, 1976)

The research procedure consists of seven steps: determining the research topic, choosing the type of publication to be collected, collecting the results of the study or literature, recording the research variables, calculating the effect size for each source or literature, interpreting the report, and making conclusions.

3. RESULTS AND DISCUSSION

The results obtained are a calculation of how much the summary effect influences the STEM Approach on Students' critical thinking abilities based on four the moderator variable is the learning model used, teaching materials or media used, materials and educational levels.

3.1. The effect of the STEM Approach on Students' Critical Thinking Skills

The results of 16 articles that met predetermined criteria regarding the effect of the STEM approach on students' critical thinking ability, found various effect sizes that varied. The effect size of each analyzed article can be seen in Table 3.

Table 3. Effect size of each article

Code Article	d	V_d	SE_d	Category
J01	2.56	0.121	0.348	Very high
J02	3,26	0.086	0.294	Very high
J03	2.44	0.114	0.337	Very high
J04	0.45	0.064	0.253	Medium
J05	3,41	0.194	0.441	Very high
J06	1.05	0.048	0.220	High
J07	0.55	0.065	0.255	Medium
J08	0.80	0.089	0.298	High
J09	4.37	0.036	0.190	Very high
J10	0.21	0.009	0.093	Low
J11	0.60	0.031	0.175	Medium
J12	0.60	0.069	0.262	Medium
J13	0.61	0.056	0.238	Medium
J14	0.51	0.070	0.265	Medium
J15	0.47	0.037	0.192	Medium
J16	0.36	0.041	0.202	Low

where:
d = Cohend's effect size
V_d = Cohend's effect size variance
SE_d = Cohend's standard error effect size

There are 5 articles with a very high effect size, 2 articles in the high category, 7 articles in the medium category, and 2 articles in the low category. Therefore, it is crucial to analyze the overall effect size of the STEM approach's effects on students' capacity for critical thought as well as the moderator factors that have been established, namely learning models, teaching materials or media, subject matter, and level of education.

The use of the STEM approach in learning science and physics in junior and senior high schools is able to improve students' critical thinking skills. As explained by Asigigan and Samur, STEM practice positively improves students' critical thinking skills (Asigigan & Samur, 2021) . The conclusion that STEM practices improve students' critical thinking abilities is supported by a number of research in the literature (Hacioglu & Gulhan, 2021; Mutakinati et al., 2018).

3.2. The Influence of The STEM Approach on Students' Critical Thinking Skills Based on The Learning Model

The description from table 4 explains that the meta-analysis of the use of the STEM approach to students' critical thinking skills based on the learning model used gives an effect with medium, high, and very high categories. The summary effect size of the influence of the STEM approach using various learning models on students' critical thinking skills can be seen in Table 4.

Table 4. Summary of the effect size of the STEM approach on students' critical thinking skills based on the learning model

Learning model	N	Summary ES	Category	p.s	95% Confidence Interval	
					Lower	Upper
STEM	10	1,087	High	0.000	0.461	1,714
Blended Learning	1	3,237	Very high	0.000	2.665	5.309
PBL	3	0.574	Medium	0.002	0.217	0.932
PJBL	1	1.024	High	0.000	0.603	1.229
Discovery Learning	1	4,357	Very high	0.000	3.985	7.847

If the p-value = 0 < 0.05, then the hypothesis tested using the fixed effect is rejected. So that there is an influence of the STEM approach on students' critical thinking skills in science and physics learning in all learning model analyzed. The highest influence of the STEM approach was found in the discovery learning model with a summary effect size of 4.357, the second highest in the Blended Learning model with a summary effect size of 3.237, the PJBL model in the high category with a summary effect size of 1.024, and so on, followed by the PBL model with a summary effect size of 0.574.

The learning model is a design that is arranged systematically to achieve the goals of learning (Alistiana et al., 2020). STEM learning is effectively combined with Discovery Learning, Blended Learning, and PJBL models because the STEM-based Discovery Learning Model in Biology that is linked to real life is in a good category, thereby increasing the interest and activeness of students and making material easier to remember, as well as ensuring that participants have good concentration during learning (Fadlina et al., 2021).

3.3. The influence of the STEM approach on students' critical thinking skills based on the teaching materials/media used

The results of further research in this research activity are related to the summary effect size analysis of the influence of the STEM approach on learning science and physics through the use of teaching materials or learning media. The summary effect size of the influence of the STEM approach using various teaching materials on students' critical thinking skills can be seen in Table 5.

Table 5. Summary of the effect size of the STEM approach on students' critical thinking skills based on the teaching materials/media used

Teaching Materials	N	Summary ES	Category	p.s	95% Confidence Interval	
					Lower	Upper
Schoology	1	3.237	Very high	0.000	2.665	5.309
Students’ worksheets	4	2.637	Very high	0.002	0.931	4.344
PhET	1	0.787	High	0.007	0.212	0.501
Digital Books	1	0.440	Medium	0.079	-0.050	-0.036

The p-value test obtained is smaller than α (0.05), which means that the null hypothesis is rejected when it is tested for schoology or media, student worksheets, and PhET. However, the results of testing the null hypothesis for digital book media show that the null hypothesis is accepted because the p-value is greater than α (0.05). This means that using instructional materials or media in learning with the STEM approach to students' critical thinking skills has a very significant influence on teaching materials or schoology media, students' worksheets, and PhET. Based on the summary effect size value that has been obtained, the highest summary effect size value is on teaching materials, school media, and students' worksheets. So, using instructional materials or media in learning with the STEM approach to students' critical thinking skills has a very significant influence on teaching materials or schoology, students' worksheets, and PhET.

In the world of education, the teaching and learning process is very dependent on factors that affect the quality of the learning process. The quality of learning can be seen in students' responses to the media or teaching materials used (Izzah et al., 2021). One of them is learning media, or learning aids, which are very important to use to communicate messages from the sender to the recipient so that the learning process can achieve learning objectives effectively by stimulating students' thoughts, feelings, interests, and readiness (Ariska et al., nd).

3.4. The Influence of the STEM Approach on Students' Critical Thinking Skills Based on Subject Matter

In the Summary Effect Sizes in Table 6, which is 4.38, it is presented that the meta-analysis results of the influence of the STEM approach on students' critical thinking ability have different effects ranging from low to very high categories on natural science learning materials and physics in middle and high school. The summary effect size of the influence of the STEM approach using various subject matter on students' critical thinking skills can be seen in Table 6.

Table 6. Summary of the effect size of the STEM approach on students' critical thinking skills based on the subject matter

Subject Matter	N	Summary ES	Category	p.s	95% Confidence Interval	
					Lower	Upper
Sound Wave	1	2.528	Very high	0.000	1.854	-0.036
Light waves	1	2.386	Very high	0.000	0.212	3.520
Light and Optics	1	0.440	Medium	0.079	-0.050	-0.036
Optical	1	0.787	High	0.007	0.212	0.501
Dynamic Fluids	2	1.713	Very high	0.000	1.336	2.09
Static Fluids	2	0.775	High	0.000	0.506	1,043
Motion System	1	4.357	Very high	0.000	3.985	7.847
Ecosystem	1	0.213	Low	0.022	0.031	0.070
Newton's laws	1	0.589	Medium	0.023	0.083	0.229
Electricity (Energy Transformation)	1	0.501	Medium	0.055	-0.010	0.048
Equilibrium	1	0.346	Low	0.078	-0.039	-0.037

The results of testing the null hypothesis on the material sound waves, light waves, optics, dynamic fluids, static fluids, motion systems, ecosystems, and Newton's laws show that the hypothesis was rejected because the p-value test obtained was smaller than the value of α (0.05). However, the results of testing the null hypothesis for the materials light and optics, electricity, and equilibrium show that the null hypothesis is accepted because the p-value test obtained is greater than the value of α (0.05).

This means that the STEM approach influences critical thinking skills in every material except for light and optics, electricity, and equilibrium. Based on the summary effect size value that has been obtained, the highest summary effect size is in motion system material, sound waves, light waves, and fluid dynamics. It may be concluded that the STEM approach to teaching science and physics has a significant positive impact on student's ability to think critically about these four subjects.

The application of the STEM approach is considered to be able to help improve students' critical thinking skills (Khoiriyah, 2018). The characteristics of subjects also influence the success of the STEM approach. Karakoc (2016) argues that when students think critically, they are encouraged to think independently, question hypotheses, analyze and synthesize events, and go further by developing new hypotheses and testing them against facts that occur in real life.

3.5. The Influence of the STEM Approach on Students' Critical Thinking Skills Based on Educational Level

Analysis using the fixed effect model obtained a summary effect size of 0.325 for the effect of the STEM approach on learning science and physics on students' critical thinking skills at the junior high school level, with a 95% confidence interval tested using JASP software ranging from 0.190 to 0.460. The summary effect size of the influence of the STEM approach using various educational level on students' critical thinking skills can be seen in Table 7.

Table 7. Summary of the effect size of the STEM approach on students' critical thinking skills based on the educational level

Educational Level	N	Summary ES	Category	p.s	95% Confidence Interval	
					Lower	Upper
Junior High School	7	0.325	Low	0.000	0.190	0.460
Senior High School	9	2,111	Very high	0.000	1.183	3.038

The results of the analysis using the RE model obtained a summary effect size of 2.111 for the effect of the STEM approach on science and physics learning on students' critical thinking skills at the high school level, with 95% confidence intervals ranging from 1.183 to 3.038. The results of testing the null hypothesis for both levels of education show that the null hypothesis is rejected because the p-value obtained is 0.000, which is smaller than the value of (0.05). It can be concluded that the STEM approach to science learning has a significant influence on students' critical thinking skills at the junior and senior high school levels.

Approaching STEM has a significant impact when applied to high school students. This is because the higher the level of education and the older the person, the more their ability increases. In Bujuri's (2018) research, children aged 11 to 12 years and over are experiencing a formal operational phase, where they are able to think of something that will or may happen and is abstract in nature.

4. CONCLUSIONS

Based on the meta-analysis carried out, it can be stated that there are two research results. First, the summary effect size of the effect of the STEM approach in science and physics learning on students' critical thinking skills is 1.375 in the high category, so the STEM approach in science and physics learning has a significant effect on students' critical thinking abilities. Second, the effect of the STEM approach in science and physics learning on students' critical thinking skills gives the highest summary effect size to the discovery learning model with an effect size of 4.36

in the very high category and to the use of schoology with a summary effect size of 3.24. In the subject matter of motion systems with a summary effect size of 2.56 in the very high category and at the high school level with a summary effect size of 2.11 in the very high category. It can be concluded that the STEM approach has a very high effect on students' critical thinking skills. Educators are required to be able to develop teaching materials or STEM-based learning media to improve critical thinking skills as a support when learning takes place.

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