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The Effect of STEM Integration in Science and Physics Learning on Students' Scientific Attitudes: A Meta-Analysis

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Abstract

There has been extensive research on the incorporation of STEM into science/physics education, which has the potential to influence students' scientific views positively. Previous research has significant limitations in describing the impact of STEM on science and physics education. To address the limitation, this meta-analysis research was carried out to investigate the impact of integrated STEM in science and physics education on students' scientific attitudes. The samples of this research, namely scientific publications published on a national and international basis via Google Scholar between 2018 and 2024, explore the impact of integrated STEM on students' science attitudes. The study's findings demonstrated that incorporating STEM into science and physics instruction significantly influenced students' scientific attitudes. In terms of educational level, STEM integration in learning science and physics has a significant impact on students' scientific views, particularly at the elementary and high school levels. When science and physics are contrasted, STEM integration in physics learning outperforms STEM application in science education. It has the greatest impact on students' critical thinking and creativity when viewed through the lens of the scientific attitude of incorporating STEM into science and physics education.

Keywords: Meta-Analysis, STEM, Science, Physics, Science Attitude

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INTRODUCTION

Education is one of the basic demands that every human being must have in order to maximise personal potential (Sakinah et al., 2020). Education has the potential to improve behaviour and knowledge (Astalini et al., 2019). Education can be carried out through the learning process (Aunurrahma, 2019). In the learning context, a scientific attitude plays an essential role in influencing students' performance in grasping the material and optimally fulfilling learning goals (Thahir et al., 2020), especially in science learning, such as physics. Science investigates nature and its contents, whereas physics analyses natural phenomena. A scientific attitude not only helps to comprehend scientific concepts but also develops the required critical, rational, and innovative thinking habits in everyday life. Science-based education combined with the cultivation of a scientific mindset can generate persons capable of solving complicated problems and adapting to global challenges. Students with a good attitude towards studying tend to be more diligent in order to get the best results (Astalini et al., 2019). Aside from that, a scientific attitude is the mindset that a scientist must have when presented with scientific problems. The scientific attitude of elementary school kids toward science instruction will influence their mental preparation. Essentially, a scientific mindset is the consequence of students' experiences rather than an innate trait (Saputra et al., 2023).

The evolution of students’ scientific attitudes in science education in Indonesia today varies significantly from east to west. Students’ scientific attitudes range from high to low. According to research findings, students in Eastern Indonesia have a high attitude of curiosity and enjoyment in studying science; students in Central Indonesia have a good interest in learning science; and students in West Indonesia have relatively good scientific attitudes overall (Jalaludin et al., 2024; Nugraheny, 2017; Sukmawati & Fatonah, 2018; Wibowo et al., 2020). This disparity in levels of scientific attitudes allows for innovation in science education from elementary school to university level in order to build students’ scientific attitudes. The incorporation of STEM in the learning process is one example of a possible learning innovation.

STEM is one learning strategy that may be used to promote student participation in the learning process and foster a positive scientific attitude. The National Science Foundation (NSF) coined the phrase STEM in 1990 as an abbreviation for Science, Technology, Engineering, and Mathematics, but the concept gained popularity in 2003 (Yllana-Prieto et al., 2021). Science is a systematic study of the qualities and behaviour of matter and the physical world based on observations, experiments, and measurements, as well as the establishment of laws to characterise general facts (Ijirana et al., 2022). The application of STEM learning may develop human resources who can think critically, logically, and methodically, as well as boost students' interest in studying (Thahir et al., 2020). STEM education focuses on three key points: (1) removing barriers between scientific fields, (2) integrating multidisciplinary sciences, and (3) providing learning experiences that are relevant to real-world challenges in everyday life. The STEM method can help students build scientific and technology skills, which is a key goal in 21st-century learning. STEM encompasses various scientific areas, including science, technology, engineering, and mathematics. (mathematics). These four disciplines can work together to solve challenges that arise in daily life (Sirajudin et al., 2021).

The implementation of STEM in science learning has a positive impact on pupils' scientific attitudes (Y. E. E. Putri et al., 2022). Science study combined with STEM can have a great impact on students' curiosity (Kholifah et al., 2018). Aside from that, STEM-based physics learning is an effective way to increase students' scientific thinking skills. The application of this strategy affects students' medium-level scientific reasoning abilities (Nurya et al., 2021). The STEM approach to physics training has also been proven to have a major impact on students' critical thinking skills (Fadlina et al., 2021), as well as their creativity (Sinurat et al., 2022). There has been much research on the integration of STEM in science/physics learning, which has the potential to positively influence students' scientific attitudes and hence serve as a remedy to students' low scientific attitudes in science/physics learning.

Previous research has several limitations, such as the implementation of STEM integration being restricted to only one level of education. Additionally, prior studies primarily focused on analysing the impact of STEM integration in science/physics learning on specific dimensions of scientific attitudes while employing only one learning model. To address these limitations, this study aims to synthesise findings from multiple related studies to examine the overall effect of STEM integration in science/physics learning on students' scientific attitudes using the analytical eye method.

Meta-analysis is a research method that examines empirical studies completed by previous researchers. This method entails summarising, integrating, synthesising, and analysing the results of selected investigations within a certain scientific topic (Retnawati et al., 2018). The meta-analysis method was chosen for this study for several reasons: first, there is a significant amount of research investigating the impact of integrating STEM in science/physics learning on students' scientific attitudes; second, there is a lack of studies that collectively analyse multiple similar articles about the effect of STEM integration in science/physics learning on students' scientific attitudes.

Building on the aforementioned points, this meta-analysis study aims to examine the impact of multiple related studies on students' scientific attitudes concerning STEM integration in science/physics learning while considering educational levels and various aspects of scientific attitudes.

METHODS

This study employed a quantitative meta-analysis method. Its objective was to examine various national and international journal articles, as well as papers from national and international conference proceedings, related to the same topic. The selected articles met specific criteria, including research publications with a DOI, published between 2018 and 2024, including samples ranging from elementary schools to universities and providing sufficient information for meta-analysis, as well as descriptive statistics for estimating effect size.

The articles for this study were collected using the Publish or Perish (PoP) software, and all selected articles were sourced from Google Scholar. The study involved three types of variables: independent, dependent, and moderator variables. The STEM approach served as the independent variable, while students' scientific attitudes were the dependent variable. The moderator variables included science and physics subjects, education level, and specific aspects of scientific attitudes.

The research technique begins with choosing the research topic, determining the period and criteria for articles to be studied, gathering relevant articles, coding the article data that has been collected, and finally analysing the effect size value of each article and concluding the analysis. A statistical equation is utilised to calculate the effect size, as shown in Table 1.

Table 1. Becker and Park's (2011) Effect Size Calculation

No	Statistic Data	Formula	Code
1	Average in a single group	$ES = \frac{\bar{x}_{post} - \bar{x}_{pre}}{SD_{pre}}$	Fr-1
2	The average for each group	$ES = \frac{\bar{x}_{eksperimen} - \bar{x}_{kontrol}}{SD_{kontrol}}$	Fr-2
3	The average for each group	$ES = \frac{(\bar{x}_{post} - \bar{x}_{pre})_E - (\bar{x}_{post} - \bar{x}_{pre})_C}{\left(\frac{SD_{preC} + SD_{preE} + SD_{postC}}{3}\right)}$	Fr-3
4	Chi-Square	$ES = \frac{2r}{\sqrt{1-r^2}}; r = \sqrt{\frac{x^2}{n}}$	Fr-4
5	t-test	$ES = t\sqrt{\frac{1}{n_E} + \frac{1}{n_C}}; ES = \frac{t}{\sqrt{n}}$	Fr-5

(Khoiri, 2019)

Following the determination of the effect size (ES), the results can be interpreted as a criterion, as shown in Table 2.

Table 2. Cohen's (1988) Effect Size Categorization

Effect Size (ES)	Standard Category
$0 \leq ES \leq 0.2$	Low
$0.2 \leq ES \leq 0.8$	Moderate
$ES \geq 0.8$	High

(Becker, 2000)

RESULTS & DISCUSSION

Table 3. Recapitulating the Influence of STEM-Integrated Physics and Science Learning on Scientific Attitudes

Code	Resource	Subject Learning	School Level	ES	Category	Formula Code
A1	(Sandi, 2021)	Physics	SHS	0.54	Moderate	Fr-5
A2	(Nurya et al., 2021)	Science	JHS	0.56	Moderate	Fr-5
A3	(Nurazmi & Bancong, 2021)	Physics	SHS	3.24	High	Fr-5
A4	(Sakinah et al., 2020)	Science	ES	4.31	High	Fr-5
A5	(Kholifah et al., 2018)	Science	JHS	1.13	High	Fr-5
A6	(Sutiyatmini & Maryanto, 2018)	Science	JHS	1.01	High	Fr-2
A7	(Ridlo et al., 2020)	Science	UN	0.78	Moderate	Fr-3
A8	(C. D. Putri et al., 2020)	Physics	SHS	3.09	High	Fr-3
A9	(Fadlina et al., 2021)	Science	SHS	3.50	High	Fr-2
A10	(Sinurat et al., 2022)	Physics	SHS	4.25	High	Fr-3
A11	(Mawarni & Sani, 2020)	Physics	SHS	0.63	Moderate	Fr-3
A12	(Rahardhian, 2022)	Physics	JHS	2.62	High	Fr-5
A13	(Fitriyah et al., 2021)	Science	SHS	1.13	High	Fr-5
A14	(Thahir et al., 2020)	Physics	SHS	1.02	High	Fr-2
A15	(Sirajudin et al., 2021)	Science	UN	4.03	High	Fr-2
A16	(Shofiyah, Wulandari, & Mauliana, 2022)	Science	UN	0.85	High	Fr-4
A17	(Shofiyah, Wulandari, Mauliana, et al., 2022)	Science	ES	0.84	High	Fr-4
A18	(Mawaddah et al., 2022)	Science	ES	1.58	High	Fr-5
A19	(Suganda et al., 2023)	Physics	SHS	1.86	High	
A20	(Wiratman et al., 2023)	Science	ES	2.8	High	Fr-1
A21	(Sawu et al., 2023)	Science	JHS	1.54	High	Fr-3
A22	(Mabrurah et al., 2023)	Physics	SHS	2.17	High	Fr-5
A23	(Khalil et al., 2023)	Physics	SHS	0.79	Moderate	Fr-2
A24	(Kerdsub & Pimvichai, 2023)	Science	JHS	0.26	Low	Fr-5
A25	(Nisah et al., 2024)	Physics	SHS	1.97	High	Fr-1
A26	(Abdurrahman et al., 2023)	Physics	SHS	0.38	Moderate	Fr-3
	Average of Effect Size			1.80	High	

School Level: ES (Elementary School); JHS (Junior High School); SHS (Senior High School); UN (University)

The analysis of the impact of the STEM-integrated science and physics curriculum on students' scientific attitudes serves as the foundation for future study. According to the research method, 26 articles were analysed so that the effect size value could be calculated based on four categories: education level, subject matter (science and physics), and dimensions of scientific attitude (curiosity, critical thinking skills, creativity, and the ability to collaborate). Table 3 summarises the impact of STEM integration in physics and science education on students' scientific views.

According to Table 3 of 26 articles, the introduction of integrated STEM science and physics education has a substantial impact on students' scientific attitudes. This implies that employing the STEM method of learning can positively improve students' attitudes towards science (Fitriansyah et al., 2021). Integrating STEM in physics education can also improve students' scientific attitudes because the application of STEM in learning necessitates students' ability to integrate the four aspects of STEM into the learning process, encouraging students to hone their thinking abilities (Thahir et al., 2020).

The Effect Size Based on School Level

Table 4. Recapitulation of the Impact of STEM Integrated Physics and Science Learning on Scientific Attitudes Based on Educational Level

School Level	Code	Average of ES	Category
Elementary School	A4, A17, A18, A20	2.38	High
Junior High School	A2, A5, A6, A12, A21, A24	1.19	High
Senior High School	A1, A3, A8, A9, A10, A11, A13, A14, A19, A22, A23, A25, A26	1.89	High
University	A7, A15, A16	1.88	High

Overall, STEM has a reasonably high impact on students' scientific views across all four levels of education, particularly at the elementary and senior high school levels. At the primary and similar levels, the employment of STEM in conjunction with other learning media can boost students' traits, particularly curiosity (Sakinah et al., 2020). STEM education at high school and similar levels can help pupils develop their 21st-century skills, which are also linked to their scientific attitudes (Baran et al., 2021). STEM-based learning can improve student traits such as discipline, curiosity, communication skills, and collaboration (Yulianti et al., 2019).

Aside from high school, including STEM in junior high school can increase pupils' scientific attitudes (Fitriansyah et al., 2021). STEM can also help students become inventors, logical thinkers, innovators, self-sufficient, and effective problem solvers, allowing them to find and construct new information (Rahardhian, 2022).

Effect Size Based on Subject Learning

Table 5. Recapitulation of the Impact of STEM Integrated Physics and Science Learning on Scientific Attitudes Based on Subject Learning

Subject Learning	Code	Average of ES	Category
Science	A2, A4, A5, A6, A7, A9, A13, A15, A16, A17, A18, A20, A21, A24	1.74	High
Physics	A1, A3, A8, A10, A11, A12, A14, A19, A22, A23, A25, A26	1.88	High

Depending on the topic, the use of STEM in students' scientific attitudes has a significant impact on both the field of science in general and physics. The application of STEM in physics education has a greater influence on students' scientific attitudes.

Students must be able to think critically in order to solve difficulties in science (Indriyana & Susilowati, 2020). The use of STEM in the learning process can help students grasp topics better, allowing them to participate more actively in the learning process (Nhung & Hanh, 2021). The use of STEM in physics education can positively impact students' scientific attitudes (Y. E. E. Putri et al., 2022). This is demonstrated in one of the previous research studies when students responded positively to the usage of STEM in physics education (Wibowo, 2018).

Effect Size Based on Scientific Attitude Aspects

Table 6. Recapitulation of the Impact of STEM Integrated Physics and Science Learning on Scientific Attitudes Based on Scientific Attitude Aspects

Aspect	Code	Average of SE	Category
Curiosity	A4, A5, A6, A24	1.59	High
Critical Thinking	A1, A2, A3, A6, A8, A9, A12, A13, A19, A20, A22, A24, A25, A26	1.80	High
Creativity	A5, A7, A10, A11, A13, A15, A21, A23, A24	1.65	Tinggi
Cooperation/ Collaboration	A1, A16, A17, A18	0.95	High
Other	A14, A24	0.63	Moderate

The scientific attitude comprises the ability to think critically, be innovative, work together, and be curious. The use of STEM in the learning process can have a significant impact on this aspect, especially on pupils' critical thinking and creativity.

STEM is an approach that can help pupils develop their critical thinking abilities (F. S. Putri & Istiyono, 2017); this is because the learning activities are more student-centred, encouraging pupils to think critically (Indriyana & Susilowati, 2020). Students can display creative thinking talents by providing solutions, justifications, or theories for an issue in order to make conclusions. This capacity should be developed in students (Sirajudin et al., 2021). STEM-based learning can make the learning process more engaging, innovative, and motivating (Fadlina et al., 2021). STEM can help children enhance their critical and creative thinking skills (Ridlo et al., 2020). Students' curiosity might be piqued through an engaging learning experience. STEM-based learning may engage pupils' interest (Kholifah et al., 2018).

Aside from that, including STEM in education can help pupils enhance their critical thinking and collaboration skills (Sandi, 2021). STEM in the learning process can prepare students for work-related qualities such as teamwork (Rusnayati et al., 2018). The use of STEM in the learning process, which sometimes requires students to study in groups, necessitates students' ability to collaborate effectively, such as by conducting research and creating specific products (Nhung & Hanh, 2021).

Overall, these findings indicate that STEM integration can improve students' scientific attitudes, serving as a solid foundation for the development of critical and social skills. Thus, the use of STEM is one of the educational methodologies that promise to generate persons with positive scientific attitudes who can think critically, innovate, and interact effectively in the current world.

CONCLUSION

The conclusions of a meta-analysis of 26 similar publications about the impact of STEM in science and physics education on students' scientific attitudes are as follows: 1) The application of STEM in science and physics education generally has a high impact on students' scientific attitudes; 2) in terms of educational levels, the application of STEM has a high impact on students' scientific attitudes, especially when applied at the elementary and high school levels; 3) based on two types of subjects, science and physics, the application of STEM has a higher impact on physics education; and finally, 4) according to the characteristics of students' scientific attitudes, including STEM into science and physics education has the greatest impact on students' critical and creative thinking skills. Based on the findings of this study, it can be concluded that STEM is one of the most effective approaches for improving students' scientific attitudes during the learning process, as evidenced by various studies on the subject, which can be used as a foundation for incorporating STEM into science and physics education. However, this study has significant limitations, including the fact that it only examined certain variables of scientific attitudes and focused solely on science and physics instruction. As a result, future studies should include evaluations of additional elements of scientific attitudes and a variety of topics.

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