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The Effect of STEM Integrated Inquiry Models in Improving Student Science Learning Outcomes (A Meta-Analysis)

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ABSTRACT
21st-century learning emphasizes the mastery of knowledge as a whole through the investigation of several points of view of knowledge, one of which is inquiry and STEM models. This study aims to determine the magnitude of the size of 20 studies on the effect of STEM-integrated inquiry models on science learning and learning outcomes. The moderator variables considered are education level and type of publication. The analyzed studies were obtained from Google Scholar and ERIC databases between 2013 and 2023. The results of the analysis showed that the influence of the STEM integrated inquiry model in physics learning on student learning outcomes had an average effect size value of 0.78 which was included in the medium category, based on 20 studies that had been collected. The distribution of studies discussing STEM-integrated inquiry models was most found in 2020 and international journals. The influence of STEM looks different at each level of education, with a significant dominance of influence occurring at the high school level.

INTRODUCTION

In the era of the 21st century, the need to produce quality education is increasing, especially in Indonesia. Good and quality education will provide the skills and knowledge needed to face the challenges of an increasingly complex era [1]. 21st-century learning should focus on developing skills and abilities that are relevant to the needs of society and the world of work today, such as critical, creative, and innovative thinking skills, good communication skills, and being able to solve problems in various corners of the field of science [2]. In addition, good and quality learning must be based on scientific concepts and avoid misconceptions [3] [4] [5]. 21st-century learning must also be supported by modern technology that can facilitate more effective and efficient learning [6].

Physics is one of the branches of science behind the birth of technology [7]. Physical science discusses a variety of natural phenomena that occur in everyday life [8] [9]. However, physics learning is not only limited to one sub-discipline. Integration in various fields of science is needed in gaining a complete understanding [10]. The learning of physics is closely related to the process of inquiry. Learning physics related to the process of inquiry can help students understand knowledge better.

Therefore, it is important for physics teachers to design interesting and relevant learning. One form of method that can be done through implementing inquiry models in the learning process.

The inquiry model is a learning model that places students at the center of learning and promotes active and inquiry-based learning [11] [12]. In the inquiry model, students are not only given knowledge and facts, but also invited to develop critical thinking, creative thinking, and other social skills [13]. Model inquiry also allows students to experience the investigation process directly, so as to develop observation, experiment design, and data analysis skills. Through the inquiry model, students can learn in a more active way and engage in learning, so as to sharpen their understanding of the concepts and facts given in learning.

In the process of learning through inquiry requires the integration of various sub-disciplines to obtain complete knowledge [14]. One form is carried out through the application of STEM approaches in the learning process. The implementation of the STEM approach with the inquiry learning model is suitable to be applied in schools in building understanding [15]. STEM is learning that integrates science, technology, engineering and mathematics, which intersect between each of these fields of science [16]. As an approach to learning, STEM provides a renewal in creating ideas for solving problems based on four integrated disciplines [17] [18]. The integration of several fields of science in a learning process provides a broad understanding to students in solving a problem from various points of view of science [19]. Thus, the STEM approach is widely used to train students' ability to think critically and creatively [20]. Thus, the integration of STEM approaches with inquiry models will provide complete knowledge from different angles of the field through investigation.

The STEM approach with an inqury model has been widely used in producing a complete learning process involving various fields of science, so many researchers conduct studies on STEM with inquiry models. Various forms of research have reported the effects of STEM with inquiry models in learning with mixed results. The researchers found improved student learning outcomes when applying them in science learning [21] [22]. Conversely, applied learning does not increasingly impact student learning [23] [24]. In addition, applying inquiry models with STEM tightening that is not implemented properly negatively impacts student learning outcomes [23] [24].

The results of previous research data on the influence of STEM learning with inquiry models on student learning outcomes are very diverse. Mapping the results in general of the effect of STEM with inquiry models has never been done by previous research. Researchers are interested in conducting meta-analytical research to determine the effect of learning STEM-integrated inquiry learning models on student achievement. In addition, moderator analysis involves learning outcomes, education level and publication type [25]. These variables are identified as moderator variables. Therefore, this study aims to explain the influence of the STEM-integrated inquiry model on student learning outcomes and analyze the influence of the STEM-integrated inquiry model on moderator variables in the form of education level and type of publication.

METHOD

Meta-analyses, which are statistical methods, combine findings from similar individual studies to unify those results [26]. This research involves a rigorous selection process to collect and evaluate relevant studies related to the research questions posed. This meta-analysis focuses on a comparative study of the use of STEM-integrated inquiry models with other approaches. Research methods involve collecting studies, grouping, and calculating effect size [27]. The studies used in the meta-analysis were sourced from national and international journals. The search was conducted through google scholar and ERIC using STEM keywords, inquiry models and learning outcomes combined with education, learning outcomes and physics. Restrictions on searches on titles are not included in sections in articles that use these keywords. All search results were examined and assessed for use in the meta-analysis with the following criteria: 1) The publication year is in the range of 2013 to 2023, 2) The study measures the impact of the STEM integrated inquiry model on student achievement 3)

The study provides sufficient data information to calculate ES (sample size, mean, standard deviation and t value), 4) The STEM integrated inquiry model is applied to physics learning. In finding the studies used, preferred reporting items for systematic reviews and meta-analyses (PRISMA) was carried out to obtain systematic results. The flow chart of the systematic review follows PRISMA rules as shown in Fig 1.

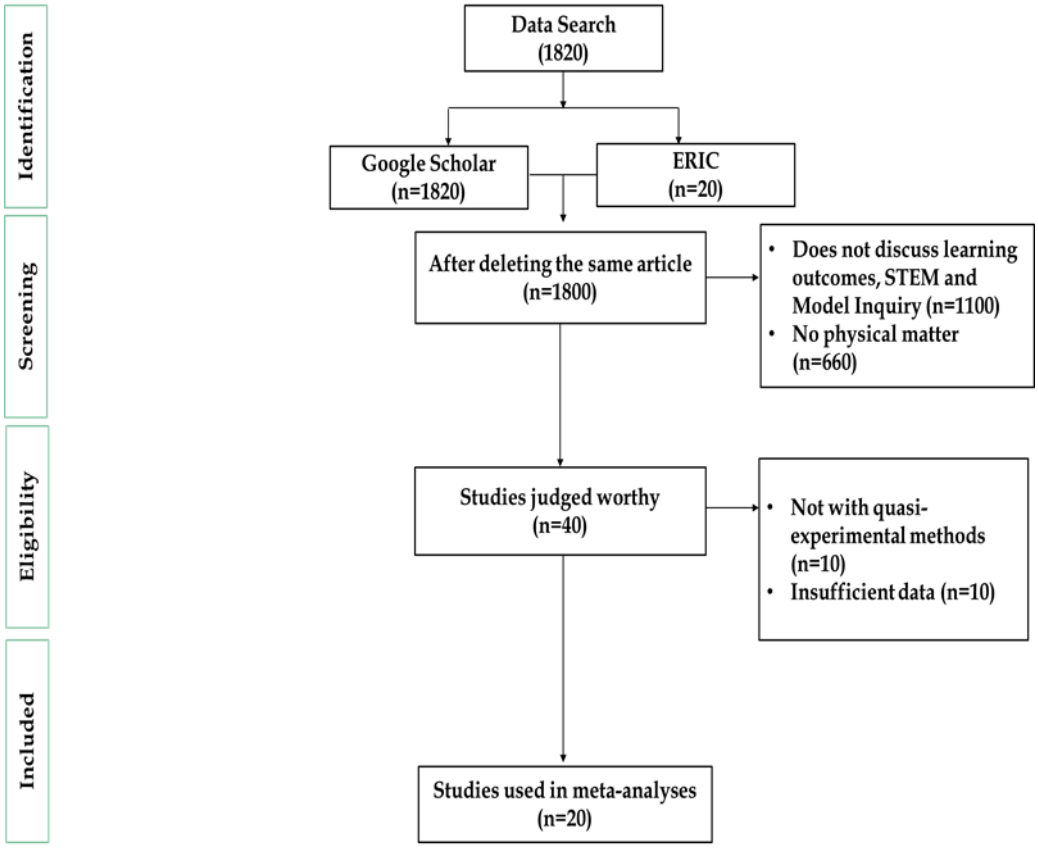

Fig 1. *Meta-analysis flow*

The meta-analysis aimed to combine quantitative data from several studies to estimate the effect of measures from STEM-integrated inquiry models on student achievement. Excel and JASP applications are used as tools to estimate the size effect. Excel applications are used to process data until size effects are found, while JASP applications are used in meta-analysis research to analyze heterogeneity, forest plots, funnel plots, and publication bias. To process the data and find the size effect, the following equation is used by taking into account the number of samples (n), the average (x), and the standard deviation (SD) as shown in equations 1 and 2.

$$d=\frac{\bar{x}_E-\bar{x}_C}{SD_W}\left(1-\frac{3}{4df-1}\right) \quad (1)$$

$$SD_W=\sqrt{\frac{(n_E-1)S_E^2+(n_C-1)S_C^2}{n_C+n_E-2}} \quad (2)$$

The value of d is the effect of the size of the data obtained and SD_w is the standard deviation. To interpret the effect size value, the effect size assessment range used is: d = 0.2 (Small), d = 0.5 (Medium), d = 0.8 (Large) [28] and d = 2.0 (Very large) [29].

RESULTS AND DISCUSSIONS

A total of 20 articles have been collected as a result of the study to be conducted meta-analysis. All articles taken meet the set criteria, namely the range of study years between 2013 to 2023, and focus on junior high school (JHS) and high school (SHS) education. The quantitative data contained in each study were used to calculate the effect measure. Table 1 displays the characteristics and effect sizes of each study.

Table 1. Characteristics of meta-analysis studies

Author	Years	Publication Type	Level	Number of Samples (n)	Effect Size (d)
Nasir et al [22]	2022	International	SHS	28	2.86
Isdianti et al [23]	2021	International	JHS	56	-0.57
Thahir et al [24]	2020	International	SHS	50	-0.85
Hudha et al [30]	2019	International	SHS	40	0.71
Sastradika [31]	2018	International	SHS	60	0.92
Yılmaz & Yanarateş [32]	2022	National	JHS	72	0.35
Wastiti & Sulur [33]	2020	National	SHS	110	1.81
Mutowiah et al [34]	2020	International	SHS	65	0.89
Uğur et al [35]	2020	National	SHS	78	1.01
Islamyah et al [36]	2018	International	SHS	66	0.77
Ong et al [37]	2020	International	SHS	136	0.16
Pahrudin et al [38]	2021	International	SHS	50	0.12
Bakirci et al [39]	2022	National	JHS	64	1.35
Kırıcı & Bakırcı [40]	2021	National	JHS	64	2.71
Ananda et al [41]	2021	International	SHS	65	0.89
Lin et al [42]	2020	International	JHS	66	0.06
Kahar et al [43]	2022	National	SHS	66	1.92
Gultom [44]	2019	National	SHS	51	0.54
Paramita et al [45]	2021	International	SHS	69	0.29
Zahara & Syukri [46]	2020	International	SHS	166	0.32
Average					**0.78**

In 2020, STEM use was most prevalent. Every year, the use of STEM research to improve student achievement increases. The integration of STEM, involving four disciplines, has proven effective in the context of learning [39]. The lowest size effect, which is -0.85, belongs to the low category, while the highest size effect, 2.86, belongs to the large category. The average effect size of the studies analyzed was 0.78, which falls into the moderate category. The results of this study are consistent with previous studies that also examined STEM relationships. The STEM mapping of students' abilities showed a score of 0.68, which was also in the medium category [47]. The application of the STEM-integrated inquiry model provides improvements in student learning outcomes [48]. Using STEM improved students' skills with an effective value of 1.16 [49]. The difference in the calculation value of the effect size value is influenced by the factor of the number of articles and the focus of the research discussed [25].

Effects of STEM Integrated Inquiry models in Improving Learning Outcomes

The results of the size effect data were used to test the meta-analysis research hypothesis. The null hypothesis presented is in the absence of the influence of STEM on student achievement. The data presented were obtained from heterogeneity tests. In the heterogeneity test, data are obtained as Q, p and I values. Q and I values are heterogeneity values. However, the value of I indicates the true heterogeneity of the data distribution. The null hypothesis will be accepted when the value of $p<0.05$. The data from the calculation of heterogeneity are shown in Table 2.

Table 2. Heterogenity Test Learning Outcomes

Variabel	Overall	95% Confidence	
		Lower	Upper
Number of Sample (K)	20		
Heterogenity test (Q)	191.9		
Probability value (p)	<0.001	0.368	1.183
Standar score (z)	37.31		
Estimate (r)	0.775		
Heterogenity test (τ^2)	0.738	0.379	1.774
Heterogenity test (τ)	0.859	0.615	1.332
Heterogenity test (I^2 %)	92.405	86.205	96.696
Heterogenity test (H^2)	13.167	7.249	30.265

The results showed that the effect size of the 20 studies analyzed was heterogeneous with a value of Q = 191.9 p < 0.001 for a degree of confidence of 95%. Thus, the random effect model is suitable to be used to type the average effect size of the study analyzed. The results of the random effect analysis showed a positive correlation between the influence of STEM use and learning achievement with a value of 0.78 in the moderate category [28]. In addition, a z score of 37.31 provides information that there is an increase in the significance of STEM use on student science learning achievement. These results align with previous research showing improved student learning outcomes [50]. STEM learning supports better mastery of students' physics concepts [51]. The presence of a STEM approach trains students to think critically in solving problems [52]. The heterogeneity results indicate the influence of moderator variables on STEM in increasing learning outcomes. In addition, based on point estimation and confidence intervals are shown in Figure 2. The magnitude of the 95% confidence level at the lowest and highest values is 0.368 and 1.183. While the average effect size value was 0.78 in the medium category.

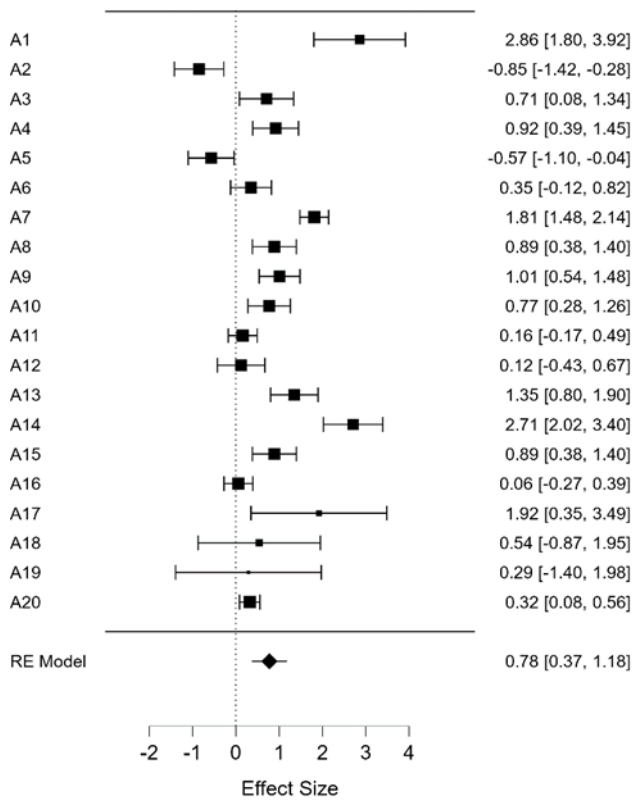

Fig 2. *Forest Plot*

Effects of STEM Integrated Inquiry model Based on Education Level

Calculations were made on combined heterogeneity (Qw) and intermediary heterogeneity (QB) to evaluate the effect of STEM based on education level. Table 3 displays the values of moderator variables that measure the effect of STEM on education level.

Table 3. Level Education

Moderator	Junior High School (JHS)	Senior High School (SHS)
K	5	15
Q	71.729	117.391
Z	1.352	3.635
d	0.763	0.777
τ^2	1.521	0.547
τ	1.233	0.739
I^2 %	96.081	89.733
H^2	25.517	9.740
95% Lower	-0.343	0.358
95% Upper	1.869	1.196
QW	189	
QB	2.1	
p-value	0.14	

STEM-integrated inquiry models in learning can be found at the junior and senior high school levels. The distribution of STEM-integrated inquiry models is most prevalent at the high school level. STEM helps junior high school students learn science, technology and math simultaneously. The smallest size effect occurred at the junior high school level with a value of 0. 763 which was included in the medium category. Meanwhile, the largest size effect occurred at the senior high school level with a value of 0. 777 which was included in the medium category. The results of other studies showed same effects that had a value of 0.68 with a medium category [47].

The p-value obtained is 0.14, which is greater than 0.05. These results show that the STEM integrated inquiry model has no significant difference when applied in middle and high school. Using STEM-integrated inquiry models in learning improves students' perceptions of the material covered. Learning implementing inquiry in the learning process can improve students' critical thinking skills, leading to improved learning outcomes [53] [54]. In line with previous research, implementing STEM in the first school positively affects learning [55]. This research is relevant to the following study, which shows not differences in learning outcomes by applying inquiry at different levels [54].

Effects of STEM Integrated Inquiry model Based on Publication Type

To evaluate the effect of the STEM integrated inquiry model based on the type of publication, calculations were made on combined heterogeneity (Qw) and intermediate heterogeneity (QB). Table 3 shows the values of moderator variables that measure the effect of the STEM-integrated inquiry model on publication type.

The use of STEM-integrated inquiry models in learning can be found in national and international journals. The distribution of STEM-integrated inquiry models is most prevalent in national journals. The distribution of journals discussing the STEM integrated inquiry model is found in 13 international journals. The p-value obtained is <0.0001, which is less than 0.05. These results show that STEM-integrated inquiry models have significant differences in publication type. Publications of STEM-integrated inquiry models are found in many international journals.

Table 3. Publication Type

Moderator	International	National
K	13	7
Q	85.112	36.8
Z	2.25	3.93
D	0.554	1.2
τ^2	0.683	0.522
T	0.826	0.722
I^2 %	92.549	85.9
H^2	13.420	7.1
95% Lower	0.072	0.617
95% Upper	1.035	1.84
QW	121.95	
QB	69.15	
p-value	<0.0001	

Publication Bias

Publication bias relates to effects that are not statistically significant [56]. In meta-analyses, publication bias can result from a variety of factors [57]. Methods used to detect publication bias include funnel plots, file drawer analysis, and Egger's regression, as shown in Table 4. The bias test results using the funnel plot, shown in Figure 3, show that bias tends to occur at the bottom of the funnel with asymmetrical results [56]. Although the distribution of size effects is difficult to identify symmetrically in the funnel plot, the value of $p<0.05$ indicates the interpretation that the distribution of size effects is symmetric. The value of $p=0.24$ exceeds the requirement limit, thus indicating a symmetrical distribution of size effects.

The integration of technology in learning has been shown to increase student motivation in learning [58]. The use of STEM in learning is also effective, STEM provides opportunities for students to think creatively in solving problems [17] [20].

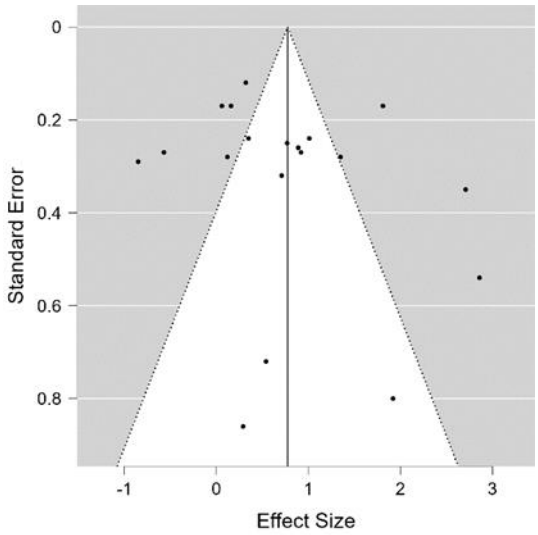

Fig 3. *Funnel plot*

Table 4. Publish bias test

Variabel	Egger's test	File Drawer Analysis	Funnel plot asymmetry
P	0.24		0.415
Fail-Safe N		1002.000	

The p value on egger's test and funnel plot asymmetry is 0.24 and 0.415. The value of p>0.05 which informs that there is no publish bias. Furthermore, the result of the fail-safe number which is a procedure for evaluating the presence of a 5K+10 publication bias with a k value is the number of studies included in the meta-analysis [59]. The fail-safe N value found was 1002,000 at a 95% confidence level through the Rosenthal procedure. This value is greater than 5K + 10, indicating no publication bias occurs [26]. Based on the results obtained, it shows no bias in all tests conducted. The published bias test results align with the interpretation of previous research by conducting egger's test, file drawer analysis, and funnel plot asymmetry to see the data synergy in the meta-analysis [60] [61].

CONCLUSION AND SUGGESTION

Based on a meta-analysis of 20 research articles, information was obtained that the STEM integrated inquiry model generally has a moderate influence on student achievement with a value of 0.78. The magnitude of the p-value < 0.05 on moderator variables at the education level and publication type showed no significant differences in each group. When viewed based on education level, it shows no significant effect based on education level. The largest STEM effect was seen at the high school education level with a score of 0.777 in the medium category. In addition, studies discussing integrated inquiry models are found in many international journals. the results of the public bias test through egger's test, funnel plot asymmetry and file drawer analysis have a value of p>0.05, meaning there is no publish bias from the distribution of data investigated in the meta-analysis.

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