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Meta analysis of the effect of STEM application on higher order thinking skill in science learning

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Abstract: The purpose of this research is to ascertain the impact of using the STEM approach in learning science and physics. The 20 research articles whose findings were examined in this study were all published in journals between 2018 and 2022. Effect size values used in the meta-analysis in this study were calculated using the OpenMEE program. Four indicators—level of education, learning models, learning media, and higher-order thinking skills—can be used to determine the impact of STEM (HOTS) learning. The average effect size on educational attainment is 1,590 at the junior high school level and 1,440 at the senior high school level. The average effect size for STEM learning with the PjBL learning model is 1.490, PBL is 1.250 and inquiry learning is 0.333. According to the average effect size results obtained for LKPD of 1.878, module of 1.818, and LKP of 1.503, this study examines the impact of STEM on the media. The average effect size score was obtained for higher order thinking skills (HOTS) for problem solving skills of 1.699, critical thinking skills of 1.899, scientific literacy abilities of 1.126, concept understanding of 0.997, and creative thinking abilities of 0.951. According to the findings of the effect size study, STEM learning is appropriate for use at the junior high school level with the PjBL learning approach using LKPD learning media to strengthen students' critical thinking skills.
Keywords: STEM; HOTS; Meta-analysis

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Introduction

In the 21st century, student competence must have been described as: Creativity, problem solving, technical literacy, innovation, critical thinking, information literacy, work and life skills, initiative, flexibility, social and cultural skills (Sarican & Akgunduz, 2018; Hacioglu & Gulhan, 2021). In addition, the educators and students must improve their science and technology knowledge in order to increase the quality of life and society in this current era of globalization. Education is the conscious and deliberate effort to create learning environments and processes that enable students to actively reach their potential. The various types of technology currently being developed are expected to increase student proficiency (Yanti et al., 2020). Students must be actively involved during the learning process. In other words, students must be enthusiastic in reading, finding information, writing, investigating and solving the problem etc.

Higher-Order Thinking Skills (HOTS) provide the ability to apply knowledge, skills, and values in reasoning, reflecting, problem-solving, decision-making, innovating, and creating something new (Yuliati & Lestari, 2018). If students are aware of their individual learning styles, they will be more motivated to perform the best of their abilities and learn faster (Dare et al., 2019). The ability of a person to think for themselves and use HOTS (Higher Order Thinking Skills) as independent

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professionals can be used to assess their talents. However, regarding the HOTS criteria, namely the capacity to think critically, creatively, and to solve issues (Nitriani et al., 2022), it is undeniable that students still struggle with critical thinking.

The aim of integrated learning in the 21st century is to equip students from an early age to achieve superior, creative, innovative and competitive achievements in the future. Science, Technology, Engineering, and Mathematics (STEM) emerged as an approach to integrating more than one subject that is actually needed by students in creating creativity (Kurup et al., 2019; Kurniati & Suyanta, 2019). Achieving success as the main goal of the STEM approach needs to involve teachers, principals, curriculum administrators, and students participation who collaborate as one unit. Teachers are the most important person that bring success in STEM implementation (Dare et al., 2019; Hudha et al., 2019; Kurup et al. 2019). This is the reason why it is important to understand the teacher's perspective, especially about how they apply STEM in their daily learning activities. Hence, teachers will know what STEM should be implemented in formal schools (Karisan et al., 2019). A student-centered approach with a focus on collaborative learning as the educational strategy associates and combines the disciplines of science, mathematics, technology, and engineering with the abilities of these fields. It has been at the core of educational advancements in recent years (Batdi et al., 2019).

A survey of the STEM education movement in Indonesia is unusual. Basically, researchers will present their research and the improvements based on the characteristics of STEM education in Indonesia to be published. In particular, more journal analysis will help other researchers broaden her knowledge of STEM education in Indonesia (Nugroho et al., 2019). Furthermore, the implementation of STEM can be used in all aspects of life, not only in education. However, there are six principles of STEM implementation in primary and secondary formal education. These principles are based on the cognitive and psychomotor development of the student's age (Kurup et al., 2019). These principles include: learning is a lifelong process; STEM is meaningful learning; STEM is taught based on the real conditions of everyday life; STEM involves the support of all educators, parents and students; and STEM will always develop by following the trend of technological developments (Falk & Needham, 2013). Media and technology play a major role in changing human life, especially in the delivery of information and knowledge in schools, and STEM is used as a means to grow skills towards the advancement of media and technology (Karnuriman et al., 2019). It is appropriate for teachers to understand the material of STEM implementation concept. In implementing STEM, teachers must know about understanding the concept, skills about STEM, and its implementation (Priatna et al., 2020; Pujiastuti & Haryadi, 2023). Based on the previus background, this review is trying to cover several purposes regarding STEM, namely: (1) the impact of STEM learning at each degree of schooling. (2) the impact of STEM learning on the learning model. (3) the impact of STEM learning on material science learning media. (4) the impact of STEM for further develop higher-request thinking abilities.

Method

A meta-analysis introduced by Glass (1976) was used to answer the research questions of this study. Meta-analysis is a systematic methodology for synthesizing knowledge from existing empirical studies to shed light on future developments in this field. Meta-analyses combine quantitative results from different studies on related topics and provide effect sizes representing the results of each study in the form of standardized mean differences (Becker & Park, 2011). This study worked on meta analysis research. Meta-investigation is research that examines the results study from a few diaries, both public and global. The articles to be analyzed are journals related to learning using the STEM model in several skills (creative thinking, understanding concepts, problem solving, scientific literacy, and critical thinking), learning models (PjBL, PBL, Inquiry), learning media (LKPD, Modules , LKP) and higher order thinking skills (critical thinking skills, conceptual understanding, problem solving, scientific literacy and creative thinking skills). The research begins with a comprehensive search of all relevant databases. The initial search began by collecting 89 journals on STEM approaches. The next step is to review the summary and text of journal articles on the metrics studied. The final results selected 20 journals eligible for meta-analysis.

There are a few steps in data processing or data analysi, namely: (1) Recording the average value of the Experiment class and Control class from each journal; (2) Recording the standard deviation of the control class from each journal; (3) Finding out the Effect Size using the OpenMEE application; (4) Determining the category of effect size obtained; and (5) Make a summary and conclusion. Impact size is a proportion of the functional meaning of exploration brings about the type of a proportion of the greatness of the connection or distinction, or the impact of one variable on another. This action supplements the insightful data given by the importance test. The rules for the impact size worth should be visible in Table 1 below:

Table 1. Criteria for the Effect Size Category

No	ES	Category
1	$ES \leq 0{,}15$	Very Low Effect
2	$ES < ES < 0{,}40$	Low Effect
3	$0{,}40 < ES < 0{,}75$	Moderate Effect
4	$0{,}75 < ES < 1{,}10$	High Effect
5	$1{,}10 < ES\ \ 1{,}45$	Very High Effect
6	$ES > 1{,}45$	High Influence

Source: (Thalheimer & Cook, 2002)

The forest plot presents information from each of the studies included in the meta-analysis and estimates of the overall outcomes. It can also be visually assessed through the degree of variability (heterogeneity) between test results (Akobeng, 2005). The specialists utilized a meta-scientific exploration plan to research whether STEM learning is viable for further developing understudy accomplishment and recognize contrasts between factors including grade level and across disciplines. Meta-investigation is a centre development to methodically incorporate quantitative outcomes from social event proof put together information depending with respect to the examination targets and accessible information (Liberati et al., 2009; Bornstein et al., 2011).

Prior to looking for peer-audited online diary articles, the specialists laid out standards for consideration and avoidance in this meta-examination. Different meta web crawlers are utilized to gather diary articles including Google, Google Researcher, Training Assets Data Centre (ERIC), and Diary Storehouse (JSTOR). Besides, the descriptors went into the meta web crawler are as per the following: the impact of STEM on HOTS abilities, instructive level, learning media, and learning models. These words are set haphazardly and on the other hand in the meta web search tool with the nonstop utilization of "STEM learning" until the review is depleted.

Research articles that are pertinent to the setting of this examination utilize a quantitative exploration plan from 2018 to 2022 disintegrated. In particular, consideration measures have been laid out in choosing diary articles, specifically: (a) research articles should be from peer-surveyed diaries distributed from 2018 to 2022; (b) should incorporate distributed references to STEM learning in the title or unique; (c) should utilize the consequences of understudy scores as the reliant variable; (d) should be at the lesser and senior secondary school levels; (e) should aim at logical trains like science and physics; and (g) should give adequate quantitative information to permit impact size computations. Diary articles were put together by evaluating for incorporation given. Figure 1 shows the pursuit interaction stream utilizing the PRISMA search system graph.

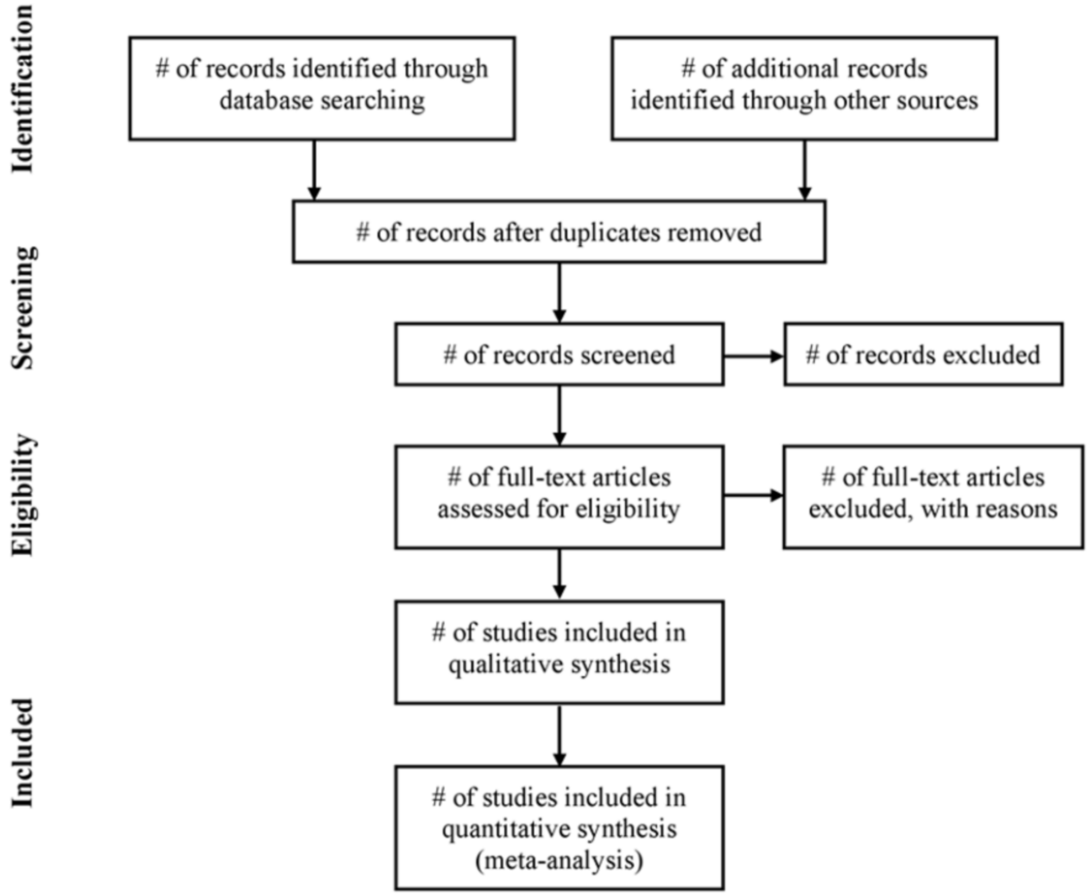

Figure 1. Flow of information through the different phases of a systematic review.

Source : (Liberati et al., 2009)

Results and Discussion

There were 10 final articles included in this analysis. The analysis of the effect of STEM on several categories obtained the effect size as follows:

The effect of STEM learning based on the level of education

In terms of the effect of STEM based on educational level, the result is presented in Table 2 below.

Table 2. The results of the effect of STEM learning based on educational level

No	Level of Education	Code	Effect Size	Average of Effect Size
1	Junior High School (SMP)	P1	1.832	1.590
		P2	1.349	
		P3	0.144	
		P11	4.222	
		P12	0.976	
		P13	0.767	
		P14	0.338	
		P15	3.369	
2	Senior High School (SMA)	P4	2.260	1.440
		P5	2.078	
		P6	2.009	
		P7	-0.170	
		P8	2.288	

No	Level of Education	Code	Effect Size	Average of Effect Size
		P9	2.097	
		P10	0.756	
		P16	1.422	
		P17	0.116	
		P18	1.559	
		P19	2.286	
		P20	1.699	

As should be visible in Table 2, the meta-examination of the impact of STEM on science and physical science learning at the middle school level, the investigation discovered that the normal impact size was 1.59 with an extremely high impact classification. In the interim, the impact of STEM for the SMA level got a typical impact size of 1.440 with a high impact classification. The outcomes showed that the utilization of STEM is all the more successfully applied to middle school level learning.

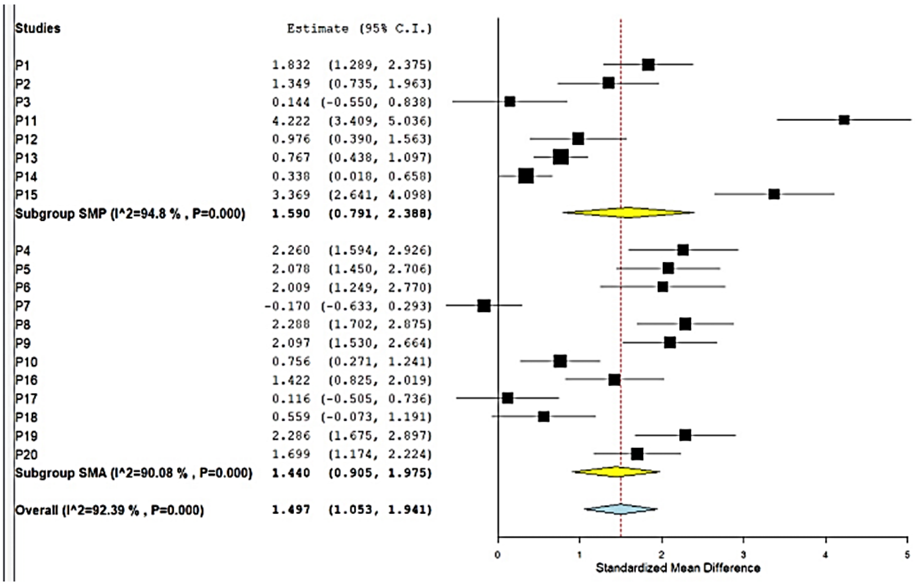

Figure 2. Forest Plot from the results of the influence of STEM on education levels

The effect of STEM learning is based on the learning model

An examination of the impact of STEM with respect to on a few learning models, as should be visible in the accompanying table.

Table 3. The results of the influence of STEM learning based on the learning model

No	Learning Model	Code	Effect Size	Average Effect Size
1	PjBL	P1	1.032	1.490
		P2	1.349	
		P3	0.144	
		P5	2.078	
		P6	2.009	
		P10	0.756	
		P19	2.286	
2	PBL	P4	2.26	1.250
		P7	-0.170	
		P20	1.699	
3	Inquiry	P17	0.116	0.333
		P18	0.559	

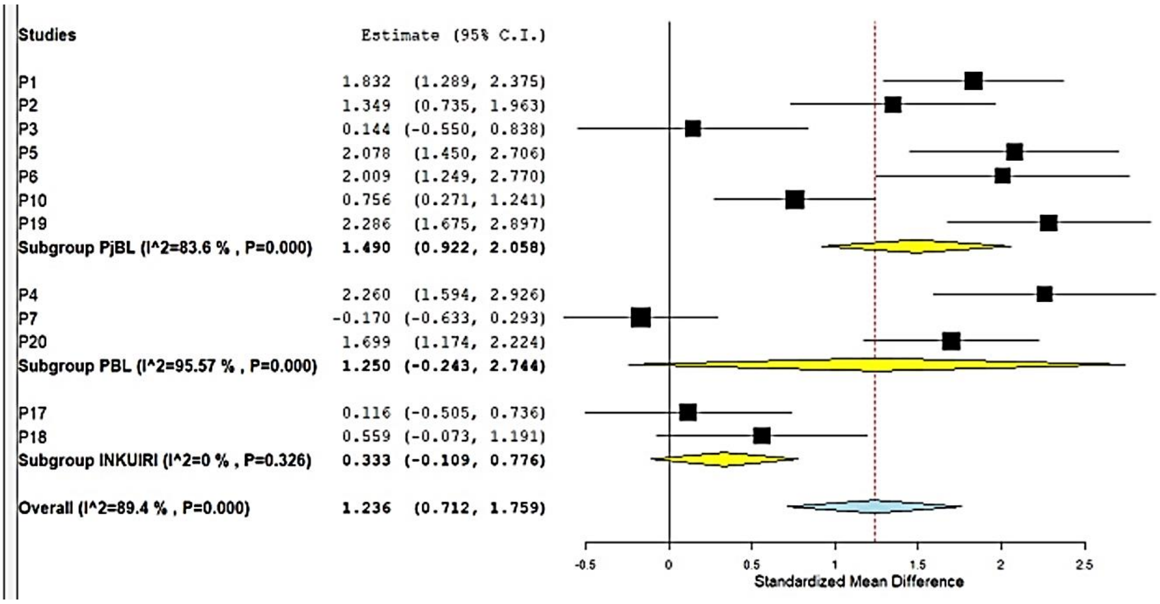

Figure 3. Forest Plot from the results of the influence of STEM on the learning model

The table showed the consequences of the meta-examination of the impact of STEM on the learning model found that in the PjBL model the normal impact size was 1.490 with an extremely high impact classification. In the interim, the impact of STEM on the PBL learning model got a typical impact size of 1.250 with a high impact classification. Concerning the request learning model, the normal impact size was 0.333 with the low impact classification. These outcomes show that the impact of STEM is all the more actually applied utilizing the PjBL learning model.

The effect of STEM learning is based on the media used

In terms of the influence of STEM learning toward the media used in learning is presented in the following table.

Table 4. The results of the effect of STEM learning based on the media applied

No	Applied media	Code	Effect Size	Average Effect Size
1	LKPD	P3	0.144	1.878
		P5	2.078	
		P11	4.222	
		P12	0.976	
		P15	3.369	
		P18	0.559	
2	Modul	P2	1.349	1.818
		P19	2.286	
3	LKP	P1	1.832	1.503
		P6	2.009	
		P10	0.756	

There are several impacts of STEM on the learning media applied. In the typical LKPD (Student Worksheet) media, the impact size is 1,878 with a very high impact class. Meanwhile for the media module, a typical impact size of 1,818 was obtained with a very high impact class, while for the LKP (Business Worksheet) a typical impact size of 1,503 was obtained with a high impact classification. Based on these results, Student Worksheets (LKPD) and modules are more widely utilized in STEM learning.

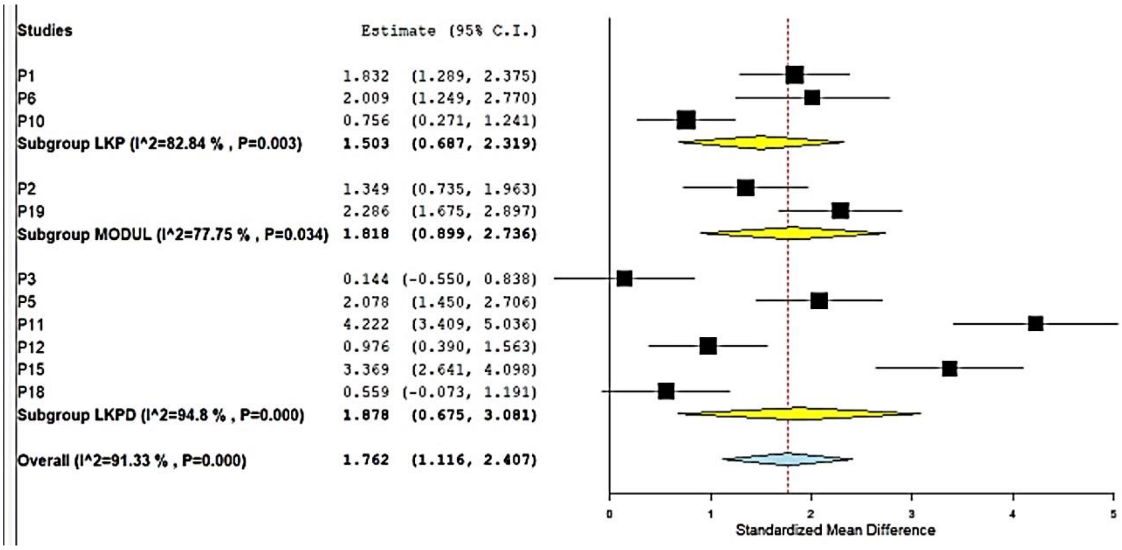

Figure 4. Forest Plot from the results of the influence of STEM on Learning Media

The effect of STEM learning based on Higher Order Thinking (HOTS) skills

The impact of STEM mastery on Level Reasoning (HOTS) skills shows a more significant effect, as can be seen in Table 5 below.

Table 5. The results of the influence of STEM learning based on Higher Order Thinking skills (HOTS)

No	Higher Order Thinking Skills (HOTS)	Code	Effect Size	Average Effect Size
1	Problem solving ability	P20	1.699	1.699
2	Critical thinking ability	P1	1.832	1.899
		P2	1.349	
		P8	2.288	
3	Scientific literacy	P9	2.097	1.126
		P12	0.976	
		P17	0.116	
		P19	2.286	
4	Concept understanding	P16	1.422	0.997
		P18	0.559	
5	Creative thinking ability	P3	0.144	0.951
		P6	2.009	
		P10	0.756	

This information presents a meta-investigation of the impact of STEM learning on some of the more significant levels of critical thinking skills (HOTS) acquired for critical thinking skills. The typical impact size was 1.699 with an extremely high impact classification. The capacity to think basically got a typical impact size of 1.899 with an exceptionally high class of impacts. Logical proficiency got a typical impact size of 1.126 with an extremely high impact classification. Understanding the idea got a typical impact size of 0.997 with a high impact class. The capacity to think inventively got a typical impact size of 0.951 with a high impact classification. In view of the outcomes over, the best impact of STEM mastering is on decisive reasoning abilities and critical thinking abilities.

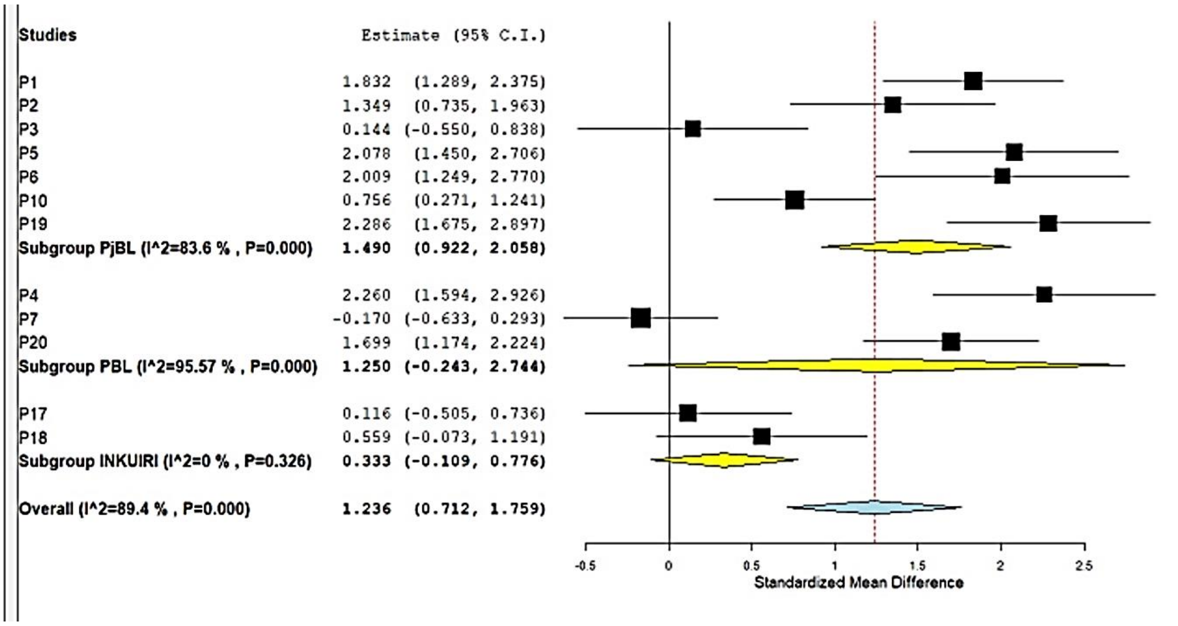

Figure 5. Forest Plot from the results of the influence of STEM on Higher Order Thinking Ability (HOTS)

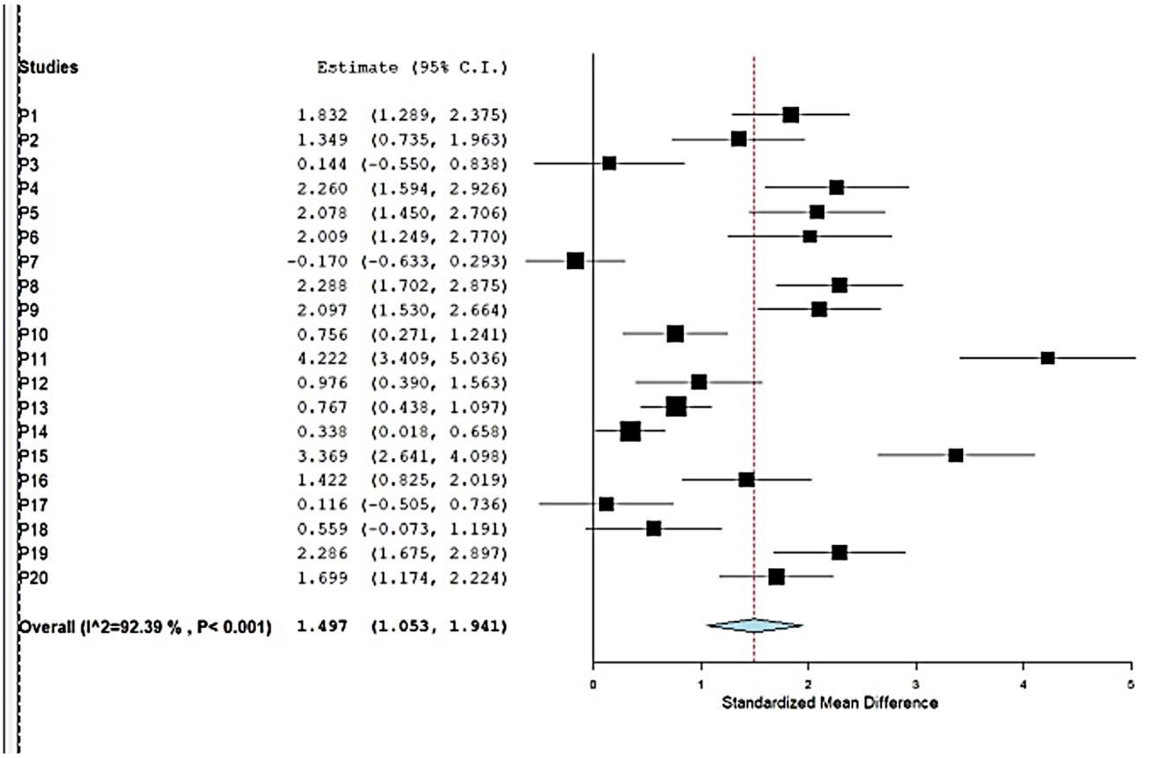

Figure 6. Table of forest plots from the results of all studies

Based on the table of the forest plots in Figure 6, the data obtained from the research plots is located to the left of zero, this means that the achievement of the control class in this study was better than that of the experimental class. Furthermore, as many as 9 literatures are to the right of zero in the range 0 to 1.45. This shows that the experimental class in this study achieved better results than the control class. While as many as 10 literatures are in the large range of 1.45, meaning that the achievement of the experimental class is much higher than the control class. The average effect size of the entire study is 1.497, meaning that STEM learning has much better results in the experimental class than the control class.

The information shows a meta-investigation of the impact of STEM learning on some Levels of more significant reasoning ability (HOTS) obtained for critical thinking skills the typical impact size is

1.699 with a very high impact classification. The ability to think basically has an average impact size of 1,899 with a very high impact rate. Logical proficiency gets a typical impact size of 1.126 with a very high impact classification. Understanding the idea of getting a typical impact size of 0.997 with a high impact class. The ability to think inventively has a typical impact size of 0.951 with a high impact classification. Judging from the results above, the best impact of STEM mastery is on decisive reasoning abilities and critical thinking skills.

Conclusion

This study found that STEM education has a huge influence on science and physics learning at the educational level. The average effect size for junior high school students is 1.590, which is greater than the average effect size for high school students. The most effective learning model is the PjBL learning model, which has a higher effect size value of 1.490, while the PBL model obtained an effect size value of 1.250 and for the inquiry learning model obtained an effect size value of 0.333. Media used in STEM learning are Student Worksheets or LKPD and LKP, which are in the very high effect category. The PjBL learning model obtained a higher effect size value of 1.490, while the PBL model obtained an effect size of 1.250 and the inquiry learning model obtained an effect size of 0.333. This review found that STEM learning is effective for improving problem solving abilities, critical thinking skills and creative thinking skills with very high effect categories. STEM objectives require understudies to have the information, mentalities, abilities to distinguish issues, make sense of regular peculiarities, plan an undertaking and reach inferences. STEM learning also has an influence on effective learning materials in straight motion and dynamic fluid materials where students can make many projects on these materials.

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