Effect of STEM on Student Learning Outcomes and Gender Differences in Senior High School: A Meta-analysis

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Abstract

This study sought to analyze the impact of the Science, Technology, Engineering, and Mathematics (STEM) approach on student learning outcomes and gender differences in senior high school. In this meta-analysis, the period for searching relevant articles was set between 2018 and 2023. The literature search was conducted through the Google Scholar database and assisted by the Publish or Perish (PoP) software program. A total of 827 papers were initially evaluated, with 14 articles meeting the criteria for inclusion in the meta-analysis from 24 studies. The analysis focused on the dimensions of learning outcomes, including knowledge, problem-solving, creativity, achievement, critical thinking, higher-order thinking skills (HOTS), science literacy, system thinking skills, self-efficacy, and cognitive. The results demonstrated that STEM education significantly enhanced student learning outcomes, with positive effects observed across both genders. However, the intensity of these effects differed between the two groups. This study offers valuable insights into the implementation of STEM in senior high schools. It also highlights the need for further research to gain a more comprehensive understanding of the impact of STEM on various dimensions, including HOTS, science literacy, and cognitive abilities. It will deepen our understanding of the overall impact of STEM.

Keywords: STEM, learning outcomes, gender, senior high school, meta-analysis.

1. Introduction

STEM is an acronym that is used to refer to the four main disciplines of science, technology, engineering, and mathematics. It encompasses a multitude of disciplines that are now beginning to have important relevance in modern education (Hinojo-Lucena et al., 2020). STEM education is an approach to teaching, learning, and integrating disciplines and skills with a focus on solving real-world problems (Wahono et al., 2020). This approach not only aims to teach theoretical concepts but also integrates practical skills through hands-on activities, thereby preparing students to face developments in the new competitive era (Usmeldi et al., 2017).

One of the principal advantages of STEM education is its capacity to integrate theoretical concepts with practical applications. This method enables students to not only gain knowledge but also to apply it in their everyday lives. This approach fosters a learning environment that is pertinent to real-world scenarios, thereby enabling students to comprehend the real-world potential of science and technology in addressing genuine challenges (Widya et al., 2019). Students frequently encounter diverse problem situations in real life and tend to address them from a single disciplinary perspective, failing to integrate knowledge from multiple disciplines

(Fadillah & Sahyar, 2023). STEM education seeks to address this limitation by instructing students to view problems from multiple perspectives and to utilize the extensive range of knowledge they possess.

The significance of STEM education is on the rise due to the necessity for interdisciplinary expertise in addressing intricate global issues (Firat, 2020). The integration of STEM into educational settings encompasses a multitude of elements with the objective of enhancing the quality of learning and the development of student's abilities. In a STEM education environment, students engage in collaborative problem-solving, which enhances their capacity for decision-making and creativity. Furthermore, these activities facilitate the enhancement of students' critical thinking and self-esteem while simultaneously imparting substantial learning (Fadlina & Ritonga, 2021). Furthermore, STEM education fosters peer interactions and enhances reasoning, collaboration, and self-regulation skills in learning (Hinojo-Lucena et al., 2020).

STEM education can be taught in four distinct ways. Firstly, as standalone subjects, where each discipline is taught separately but within the STEM framework. Secondly, by prioritizing one or two specific subjects within the STEM disciplines, allowing for a more in-depth focus on those areas. A third approach is to integrate one STEM discipline into the other three, which helps students to appreciate the interconnections between different fields of study. Fourth, by integrating the four disciplines, a truly integrated and holistic approach to learning is created (Dugger, 2010).

In addition to the diverse array of teaching methodologies employed, the rapid advancement of contemporary educational technologies and tools presents a wealth of new opportunities. It facilitates the implementation of STEM models in the educational process. The advent of modern technologies has provided educators with a plethora of tools and platforms that facilitate more engaging and interactive learning experiences for students engaged in STEM subjects. For instance, a meta-analysis conducted by Wang et al. (2022) revealed that digital games represent a promising pedagogical method in STEM education, effectively enhancing learning gains. The incorporation of digital games into the learning environment not only enhances the enjoyment of the learning process but also facilitates the acquisition of complex concepts in a manner that is more readily comprehensible and memorable.

STEM education has recently attracted considerable attention as a pivotal pedagogical approach. It serves not only to impart scientific and mathematical knowledge but also to foster a multidisciplinary perspective in problem-solving, thereby nurturing essential 21st-century skills (Widya et al., 2019). However, despite the burgeoning interest and extensive research on STEM education, there still needs to be more in the existing literature. Several studies, including those by Saraç (2018) and Wahono et al. (2020), have suggested that STEM education positively influences the quality of learning processes and student academic achievements. These investigations revealed that students engaged in STEM education exhibit improved academic performance, display a more favorable attitude towards learning, demonstrate heightened motivation, and cultivate higher-order thinking skills. Likewise, the findings from research conducted by Alatas & Yakin (2021), Çevik & Azkın (2020), and Listiana et al. (2019) corroborate the efficacy of STEM education in enhancing student learning outcomes. However, some studies have yielded disparate findings, such as those by Hansen (2014) and Judson (2014), which did not find a robust correlation between STEM education and enhanced student learning outcomes. Research conducted by Bedar and Al-Shboul (2020) also indicates that there is no significant impact on student learning motivation. Additionally, Saraç (2018) posited that further research is necessary to examine the role of gender in STEM education practices. One of the main problems associated with STEM teaching is gender disparity, with a greater proportion of males than females utilizing pedagogical techniques (Hinojo-Lucena et al., 2020; Wong et al., 2023).

Thus, this study aims to bridge existing research lacunae by examining the effects of STEM education on student academic achievements, focusing on potential gender disparities in the senior high school setting. Consequently, it is anticipated that the findings of this inquiry will not only provide valuable insights into optimizing STEM pedagogy but also play a pivotal role in mitigating the gender gap prevalent in STEM education.

3. Methods

A meta-analysis stands as a statistical technique facilitating the simultaneous and quantitative assessment of numerous studies. Its primary aim is to identify and quantify trends within quantitative findings by measuring discrepancies between control and experimental groups and deriving effect size outcomes. Through this method, the interplay between variables can be scrutinized, and patterns within the data can be discerned (Lara-Alvarez et al., 2023). In the current meta-analysis, the quest for pertinent articles spanned from 2018 to 2023. Utilizing the Google Scholar database supplemented by the Publish or Perish (PoP) software, akin to the methodologies employed by Antonio & Castro (2023) and Funa & Prudente (2021), ensured a comprehensive literature search. Employing Boolean operators, including "OR" and "AND," the search query comprised keywords such as "STEM," "experimental," "High School," and ("learning outcomes" OR "achievement"). This rigorous approach ensured the inclusion of relevant studies to ascertain a robust foundation for the subsequent analysis.

To include studies in the meta-analysis, explicit inclusion and exclusion criteria were established. Inclusion criteria stipulated that studies must (1) pertain to the topic of STEM, (2) employ experimental, quasi-experimental, or mixed methods designs with pre-test/post-test measures, and (3) provide complete research data suitable for meta-analysis. Conversely, exclusion criteria encompassed studies that (1) did not focus on senior high school education, (2) deviated from the STEM theme, (3) were published solely in conference proceedings, and (4) lacked essential primary data such as sample size, mean, and standard deviation. Adhering to the PRISMA guidelines, a flowchart was utilized during the selection process to enhance systematic review quality (Moher et al., 2009). Following meticulous screening and exclusion of ineligible literature, 15 relevant outcomes were identified and incorporated into the meta-analysis. The detailed literature screening process is delineated in Figure 1. Subsequently, 14 eligible articles were systematically coded to facilitate the attainment of research objectives.

For the meta-analysis, Review Manager 5.4 software was employed to generate a funnel plot, assessing publication bias and ensuring calculation accuracy (Hakim et al., 2023; Zuo et al., 2023). Additionally, a forest plot was utilized to ascertain the total effect size, calculated via a random effects model with a 95% confidence interval (CI). Cohen's criteria guided effect size interpretation: 0.80 and above (large), 0.50 to 0.79 (medium), 0.20 to 0.49 (small), and less than 0.19 (no effect) (Cohen, 2013). The heterogeneity of included studies was evaluated using the I^2 statistic via the Cochran Q (chi^2) test, categorized as 0% to 25% (not heterogeneous), 26% to 50% (low), 51% to 75% (medium), and more than 75% (high). The standard mean difference was selected as the effect measurement for display on the forest and funnel plots.

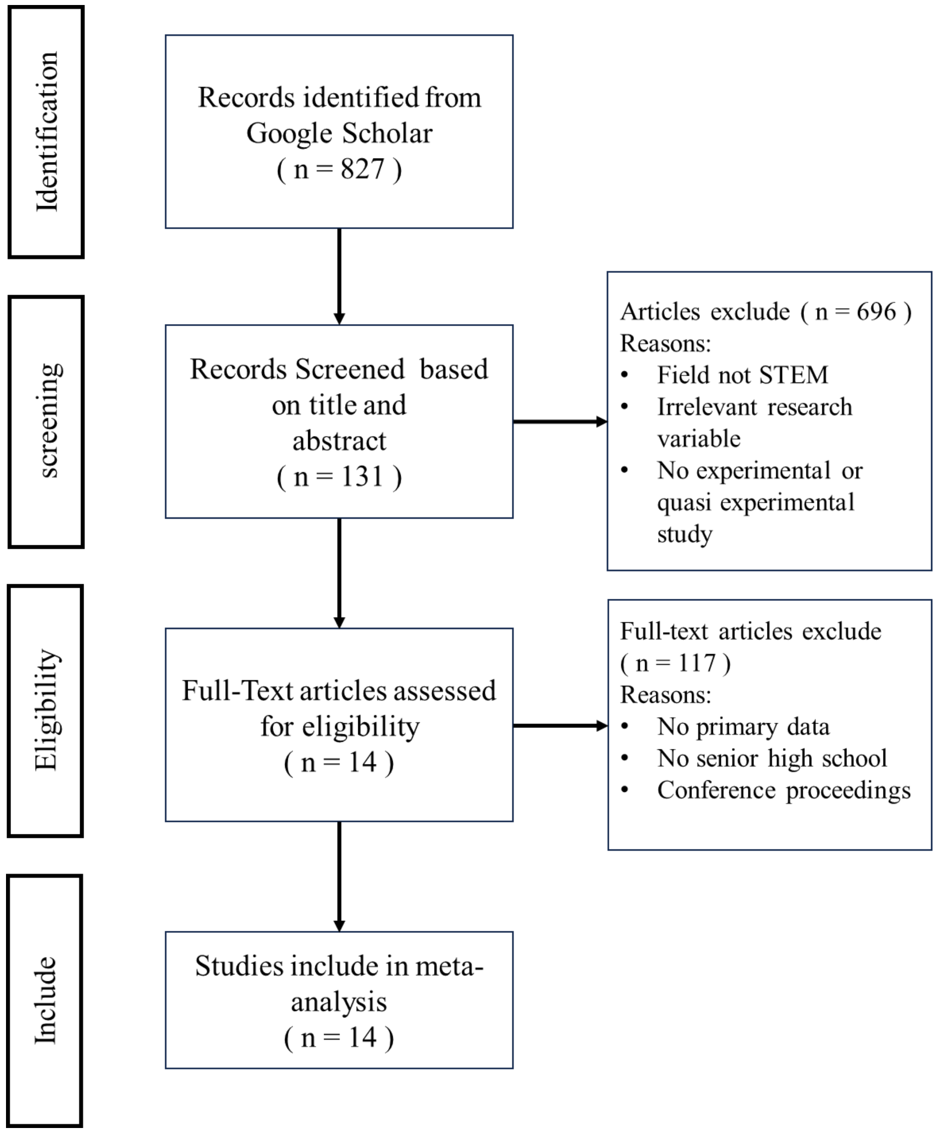

Figure 1. Diagram of the literature screening process

4. Results

Out of the 827 papers initially identified through the literature search, a total of 14 articles met the eligibility criteria for inclusion in the meta-analysis, resulting in a pool of 24 included studies. Table 1 provides a comprehensive summary of the included articles, presenting pertinent details such as the number of studies encompassed, learning outcomes examined, gender considerations, as well as the mean and standard deviation of both experimental and control group means. Figure 2 illustrates a forest plot delineating the overall effect of STEM interventions on learning outcomes, revealing a 95% confidence interval ranging from 1.26 to 2.16. Notably, the findings indicate a significant enhancement in learning outcomes attributable to STEM interventions compared to traditional learning methods ($d = 1.71$, $Z = 7.45$, $p < 0.00001$). Further statistical analysis revealed substantial heterogeneity in effect sizes across the 24 included studies ($Q = 589.66$, $I^2 = 96\%$). A funnel plot was employed to assess for publication bias to ensure the robustness of the results. As depicted in Figure 3, the funnel plot exhibits a symmetric distribution of effect sizes around the mean effect size, suggesting minimal publication bias among the included studies thereby enhancing the credibility of the conclusions drawn (Narulita & Aprilianto, 2022).

Table 1. Articles included in the study

No	Author and Year	ME	SE	NE	MC	SC	NC	NT	Learning Outcomes	Gender
1	Abdurrahman et al. (2023)	82.42	5.61	31	75.28	7.74	36	67	System thinking skills	NoR
2	Ab Kadir et al. (2021)	64.70	11.54	20	52.65	11.04	20	40	Achievement	NoR
3	Alatas & Yakin (2021)	74.51	8.36	70	49.49	19.35	70	140	Problem solving	NoR
4	Ardianti et al. (2020)	81.50	5.10	27	60.59	5.17	27	54	Critical thinking	NoR
5	Chen & Chang (2018)	76.20	23.33	42	41.00	14.26	42	84	Knowledge	NoR
6	Fadlina & Ritonga (2021)	76.37	12.20	292	36.93	12.25	292	584	Knowledge	NoR
7	Haryadi et al. (2021)	40.00	11.00	30	35.00	11.00	30	60	HOTS	NoR
8	Lin et al. (2019) (Study 1)	76.62	17.62	78	69.83	17.66	71	149	Achievement	NoR
	Litn et al. 2019 (Study 2)	13.37	2.91	78	11.92	2.81	71	149	Self-efficacy	NoR
9	Listiana et al. (2019)	0.55	0.89	35	0.49	0.10	32	67	Scientific literacy	NoR
10	Samsudin et al. (2018) (Study 1)	14.64	2.38	28	5.64	2.44	28	56	Achievement	Male
	Samsudin et al. 2018 (Study 2)	14.36	2.44	22	5.73	2.33	22	44	Achievement	Female
11	Samsudin et al. (2020)	3.53	0.25	50	3.24	0.32	50	100	Self-efficacy	NoR

No	Author and Year	ME	SE	NE	MC	SC	NC	NT	Learning Outcomes	Gender
12	Shahbazloo & Abdullah Mirzaie (2023) (Study 1)	17.31	3.16	72	14.72	3.41	71	143	Achievement	Female
	Shahbazloo & Mirzaie, 2023 (Study 2)	17.57	2.96	72	12.20	3.96	71	143	Achievement	Female
	Shahbazloo & Mirzaie, 2023 (Study 3)	161.86	47.07	72	84.75	30.35	71	143	Creativity	Female
	Shahbazloo & Mirzaie, 2023 (Study 4)	19.13	6.89	72	15.66	5.78	71	143	Creativity	Female
	Shahbazloo & Mirzaie, 2023 (Study 5)	15.37	4.42	72	12.48	3.02	71	143	Creativity	Female
	Shahbazloo & Mirzaie, 2023 (Study 6)	40.10	13.91	72	18.04	9.61	71	143	Creativity	Female
	Shahbazloo & Mirzaie, 2023 (Study 7)	87.26	31.85	72	38.58	17.36	71	143	Creativity	Female
13	Simeon et al. (2022) (Study 1)	17.69	2.64	48	10.40	2.61	48	96	Achievement	Male
	Simeon et al. 2020 (Study 2)	17.37	2.93	41	8.22	3.60	41	82	Achievement	Female
14	Sinurat et al. (2022) (Study 1)	82.81	9.99	32	36.72	8.09	32	64	Creativity	NoR
	Sinurat et al. 2022 (Study 2)	73.13	16.93	32	72.50	13.67	32	64	Cognitive	NoR

Note: mean value of experimental group (ME), standard deviation of experimental group (SE), number of experimental group (NE), mean value of control group (MC), standard deviation of control group (SC), number of control group (NC), total study population (NT), not reported (NoR).

Further calculations were performed to display the effect of STEM by subgroup. Figure 4 presents a forest plot of the influence of STEM on learning outcomes based on subgroup analysis (test for subgroup differences: $Q = 100.30$, $I^2 = 91\%$). The results show that STEM has an enormous influence with significant values and high heterogeneity on knowledge ($d = 2.53$, $Z = 3.57$, $p < 0.001$, $Q = 24.02$, $I^2 = 96\%$), creativity ($d = 1.88$, $Z = 4.81$, $p < 0.001$, $Q = 104.32$, $I^2 = 95\%$), and achievement ($d = 2.00$, $Z = 5.03$, $p < 0.001$, $Q = 137.14$, $I^2 = 95\%$). While the effect of STEM on self-efficacy is in the moderate category with a significant value, and the level of heterogeneity is also moderate ($d = 0.74$, $Z = 2.96$, $p < 0.01$, $Q = 3.40$, $I^2 = 71\%$). In addition, the influence of STEM also showed a large and significant influence on problem-solving ($d = 1.67$, $Z = 8.47$, $p < 0.001$), systems thinking skills ($d = 1.03$, $Z = 3.94$, $p < 0.001$), and the strongest influence on critical thinking (d = 4.01, Z = 8.28, p < 0.001), with heterogeneity unknown due to the limited studies included, indicating this dimension was not explored too much. At the same time, the influence of STEM on HOTS showed a small and insignificant level (d = 0.45, Z = 1.71, p > 0.05). Also, it did not influence science literacy (d = 0.09, Z = 0.37, p > 0.05) and cognitive (d = 0.04, Z = 0.16, p > 0.05), where heterogeneity could also not be calculated due to limited studies.

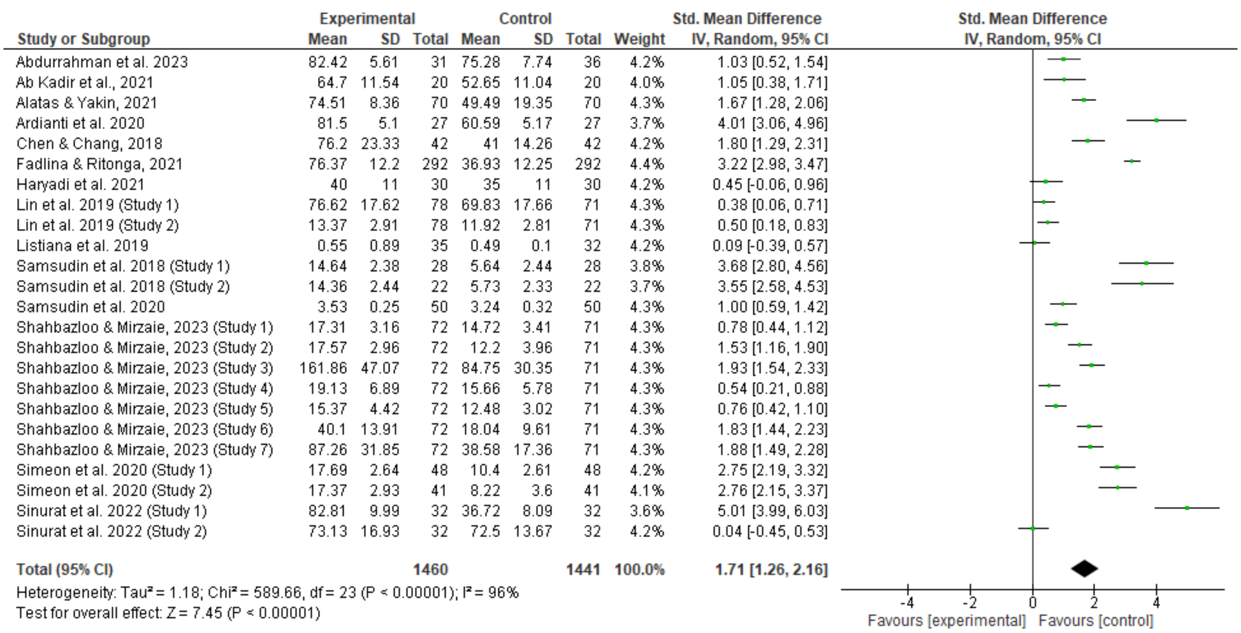

Figure 2. Forest plot of overall STEM influence

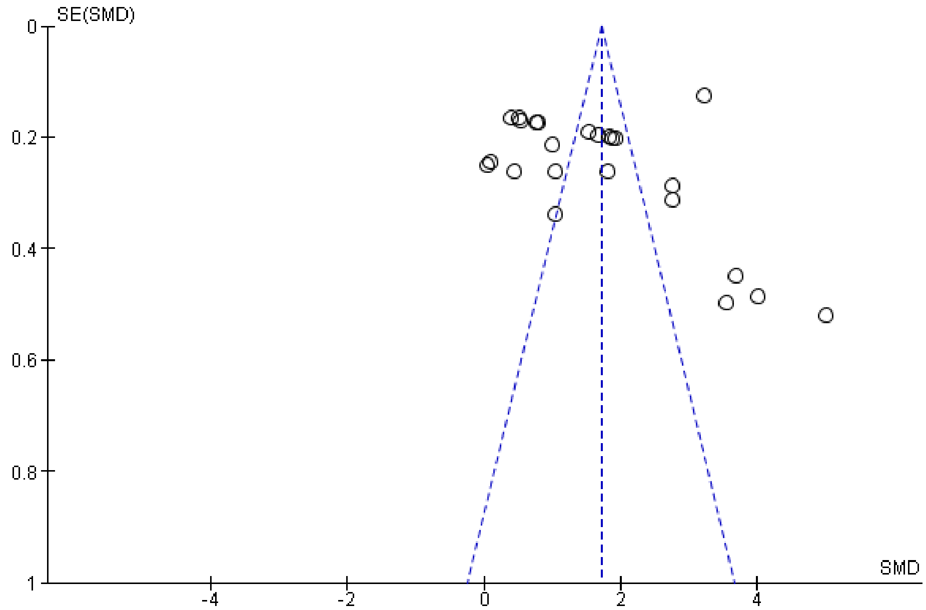

Figure 3. Funnel plot of overall STEM influence

In addition, calculations were also carried out to see the influence of STEM-based on gender. Table 1 shows that not all studies presented data on the effect of STEM on gender, with 2 studies for males and 9 studies for females. Figure 5 presents a forest plot of the effect of STEM on learning outcomes based on gender subgroup analysis (test for subgroup differences: $Q = 8.14$, $I^2 = 87.7\%$). The results showed that STEM had a large and significant effect on males ($d = 3.15$, $Z = 6.87$, $p < 0.001$) with moderate heterogeneity ($Q = 3.02$, $I^2 = 67\%$). While the influence of STEM on females was also large but lower than that of males ($d = 1.66$, $Z = 6.50$, $p < 0.001$), with high heterogeneity as more studies were included ($Q = 106.61$, $I^2 = 92\%$). Overall, STEM had a large influence with significant values and high heterogeneity by gender ($d = 1.93$, $Z = 6.50$, $p < 0.001$, $Q = 153.60$, $I^2 = 93\%$).

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
2.1.1 Knowledge								
Chen & Chang, 2018	76.2	23.33	42	41	14.26	42	4.2%	1.80 [1.29, 2.31]
Fadlina & Ritonga, 2021	76.37	12.2	292	36.93	12.25	292	4.4%	3.22 [2.98, 3.47]
Subtotal (95% CI)			**334**			**334**	**8.6%**	**2.53 [1.14, 3.92]**
Heterogeneity: Tau² = 0.96; Chi² = 24.02, df = 1 (P < 0.00001); I² = 96%								
Test for overall effect: Z = 3.57 (P = 0.0004)								
2.1.2 Creativity								
Shahbazloo & Mirzaie, 2023 (Study 3)	161.86	47.07	72	84.75	30.35	71	4.3%	1.93 [1.54, 2.33]
Shahbazloo & Mirzaie, 2023 (Study 4)	19.13	6.89	72	15.66	5.78	71	4.3%	0.54 [0.21, 0.88]
Shahbazloo & Mirzaie, 2023 (Study 5)	15.37	4.42	72	12.48	3.02	71	4.3%	0.76 [0.42, 1.10]
Shahbazloo & Mirzaie, 2023 (Study 6)	40.1	13.91	72	18.04	9.61	71	4.3%	1.83 [1.44, 2.23]
Shahbazloo & Mirzaie, 2023 (Study 7)	87.26	31.85	72	38.58	17.36	71	4.3%	1.88 [1.49, 2.28]
Sinurat et al. 2022 (Study 1)	82.81	9.99	32	36.72	8.09	32	3.6%	5.01 [3.99, 6.03]
Subtotal (95% CI)			**392**			**387**	**25.2%**	**1.88 [1.11, 2.65]**
Heterogeneity: Tau² = 0.85; Chi² = 104.32, df = 5 (P < 0.00001); I² = 95%								
Test for overall effect: Z = 4.81 (P < 0.00001)								
2.1.3 Achievement								
Ab Kadir et al., 2021	64.7	11.54	20	52.65	11.04	20	4.0%	1.05 [0.38, 1.71]
Lin et al. 2019 (Study 1)	76.62	17.62	78	69.83	17.66	71	4.3%	0.38 [0.06, 0.71]
Samsudin et al. 2018 (Study 1)	14.64	2.38	28	5.64	2.44	28	3.8%	3.68 [2.80, 4.56]
Samsudin et al. 2018 (Study 2)	14.36	2.44	22	5.73	2.33	22	3.7%	3.55 [2.58, 4.53]
Shahbazloo & Mirzaie, 2023 (Study 1)	17.31	3.16	72	14.72	3.41	71	4.3%	0.78 [0.44, 1.12]
Shahbazloo & Mirzaie, 2023 (Study 2)	17.57	2.96	72	12.2	3.96	71	4.3%	1.53 [1.16, 1.90]
Simeon et al. 2020 (Study 1)	17.69	2.64	48	10.4	2.61	48	4.2%	2.75 [2.19, 3.32]
Simeon et al. 2020 (Study 2)	17.37	2.93	41	8.22	3.6	41	4.1%	2.76 [2.15, 3.37]
Subtotal (95% CI)			**381**			**372**	**32.8%**	**2.00 [1.22, 2.79]**
Heterogeneity: Tau² = 1.17; Chi² = 137.14, df = 7 (P < 0.00001); I² = 95%								
Test for overall effect: Z = 5.03 (P < 0.00001)								
2.1.4 Self-efficacy								
Lin et al. 2019 (Study 2)	13.37	2.91	78	11.92	2.81	71	4.3%	0.50 [0.18, 0.83]
Samsudin et al. 2020	3.53	0.25	50	3.24	0.32	50	4.3%	1.00 [0.59, 1.42]
Subtotal (95% CI)			**128**			**121**	**8.6%**	**0.74 [0.25, 1.22]**
Heterogeneity: Tau² = 0.09; Chi² = 3.40, df = 1 (P = 0.07); I² = 71%								
Test for overall effect: Z = 2.96 (P = 0.003)								
2.1.5 Problem solving								
Alatas & Yakin, 2021	74.51	8.36	70	49.49	19.35	70	4.3%	1.67 [1.28, 2.06]
Subtotal (95% CI)			**70**			**70**	**4.3%**	**1.67 [1.28, 2.06]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 8.47 (P < 0.00001)								
2.1.6 System thinking skills								
Abdurrahman et al. 2023	82.42	5.61	31	75.28	7.74	36	4.2%	1.03 [0.52, 1.54]
Subtotal (95% CI)			**31**			**36**	**4.2%**	**1.03 [0.52, 1.54]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 3.94 (P < 0.0001)								
2.1.7 Critical thinking								
Ardianti et al. 2020	81.5	5.1	27	60.59	5.17	27	3.7%	4.01 [3.06, 4.96]
Subtotal (95% CI)			**27**			**27**	**3.7%**	**4.01 [3.06, 4.96]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 8.28 (P < 0.00001)								
2.1.8 Scientific literacy								
Listiana et al. 2019	0.55	0.89	35	0.49	0.1	32	4.2%	0.09 [-0.39, 0.57]
Subtotal (95% CI)			**35**			**32**	**4.2%**	**0.09 [-0.39, 0.57]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.37 (P = 0.71)								
2.1.9 HOTS								
Haryadi et al. 2021	40	11	30	35	11	30	4.2%	0.45 [-0.06, 0.96]
Subtotal (95% CI)			**30**			**30**	**4.2%**	**0.45 [-0.06, 0.96]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.71 (P = 0.09)								
2.1.10 Cognitive								
Sinurat et al. 2022 (Study 2)	73.13	16.93	32	72.5	13.67	32	4.2%	0.04 [-0.45, 0.53]
Subtotal (95% CI)			**32**			**32**	**4.2%**	**0.04 [-0.45, 0.53]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.16 (P = 0.87)								
Total (95% CI)			**1460**			**1441**	**100.0%**	**1.71 [1.26, 2.16]**
Heterogeneity: Tau² = 1.18; Chi² = 589.66, df = 23 (P < 0.00001); I² = 96%								
Test for overall effect: Z = 7.45 (P < 0.00001)								
Test for subgroup differences: Chi² = 100.30, df = 9 (P < 0.00001), I² = 91.0%								

Figure 4. Forest plot of STEM influence based on sub-group analysis of learning outcomes

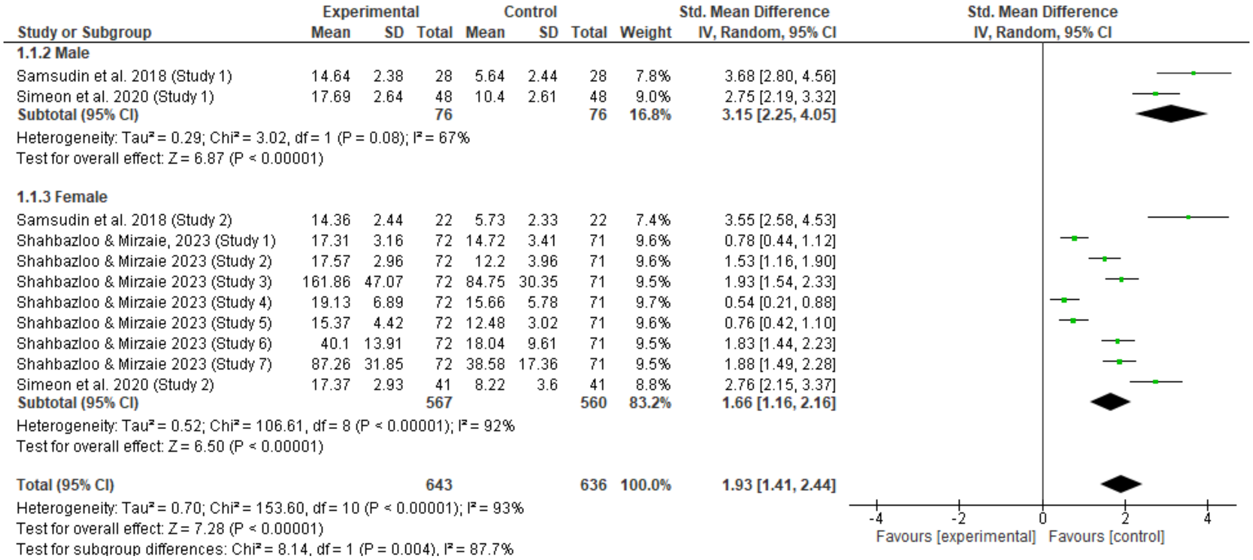

Figure 5. Forest plot of STEM influence by gender

5. Discussions

This research highlights the impact of using STEM in the context of senior high school education, particularly in relation to student learning outcomes and gender differences. The results of the meta-analysis show that the application of STEM is significantly more effective than traditional learning methods, especially in improving knowledge, creativity, achievement, and critical thinking. This meta-analysis includes studies that systematically review and synthesize data to assess the overall effectiveness of STEM education. The findings consistently show that STEM-based approaches promote more profound understanding and knowledge retention among students, which is due to the interdisciplinary nature of STEM that integrates various subjects and promotes more integrated and applicable learning experiences (Hansen, 2014; Judson, 2014). In terms of creativity, STEM education encourages innovative thinking and problem-solving by engaging students in practical projects and real-world applications, thus helping them develop creative solutions and think outside the box (Tang et al., 2020) . This enhancement is critical not only for academic success but also for preparing students for the complex problems of the future (Almulla, 2023; Zhang et al., 2018). Achievement is also a critical area where STEM education excels; data shows that students involved in STEM programs tend to perform better on assessments and standardized tests than their peers in traditional learning environments. This increase in academic achievement is linked to the active learning strategies used in STEM education, including collaborative projects, experiments, and the use of advanced technology (Usmeldi et al., 2017). In addition, STEM education significantly improves critical thinking skills; the focus on inquiry-based learning and problem-solving in STEM curricula equips students with the ability to analyze situations, evaluate evidence, and make informed decisions, which is invaluable as they navigate future educational and career paths (Fong et al., 2017).

However, the findings related to HOTS showed small and insignificant effects, along with the insignificance of STEM on science literacy and cognition, highlighting the need for further attention to understanding these dimensions in the context of STEM learning in Senior High School. It could be due to a number of factors, such as the relatively small number of studies included in the meta-analysis. Future research could involve adjusting learning strategies or further research to identify additional influencing factors that might contribute to these results. In addition, the variation in the number of studies on HOTS, science literacy, and cognition indicates the limited empirical data available to analyze in these areas. These limitations suggest that some aspects of physics learning need to be adequately explored in the existing research literature. Therefore, to gain a more holistic and in-depth understanding of the impact of STEM, further research needs to be conducted to explore these and other learning outcomes in students.

It will enable educators and policymakers to make informed decisions and develop effective strategies to optimize STEM education in senior high schools.

In the context of gender analysis, the findings show that the implementation of STEM education has a positive impact on student learning outcomes in senior high school, both for boys and girls. It is in line with the findings of Samsudin et al. (2018) who found that there was no significant difference in performance between male and female students in senior high school in STEM fields. In addition, subgroup analysis showed that STEM had a significant influence on both gender groups, albeit with different intensities. These findings are in line with the views of Saraç (2018), who highlighted the need for further research to understand the role of gender in STEM education practices. Interestingly, research has also noted that a gender gap may emerge in the use of pedagogical techniques, with men tending to use such techniques more than women (Hinojo-Lucena et al., 2020; Wong et al., 2023). The implication is that STEM implementation not only has an overall positive impact but also reveals detailed differences in participation and acceptance of these learning methods between males and females (Samsudin et al., 2018; Shahbazloo & Abdullah Mirzaie, 2023; Simeon et al., 2022). Saraç (2018) mentioned that the gender gap in STEM teaching methods is one of the main issues, and this finding adds to the understanding that STEM may need to be restructured to minimize this disparity. Although this study shows a general positive impact, further research needs to be conducted that focuses on a more in-depth investigation of the influence of STEM on gender aspects (Usmeldi et al., 2017). Thus, more inclusive learning strategies can be developed that take into account the diversity of student responses based on gender, which will ultimately shape an environment that supports equitable educational outcomes for all.

Overall, the results of this study provide a solid foundation to support the integration of STEM in learning in Senior High School. However, this study has some limitations that need to be carefully considered. First, most of the findings are based on studies that have methodological and contextual diversity. It implies that interpretation of the results should be done with caution, given the variations in research designs, samples, and measurement methods used in these studies. Secondly, high heterogeneity in some dimensions suggests significant variation among the included studies, which could be due to differences in research approaches. Therefore, it is essential to consider this diversity in interpreting the results.

In addition, specific dimensions such as HOTS, science literacy and cognition did not allow for heterogeneity to be accounted for, which adds complexity in interpreting the results. Nevertheless, the findings still make a valuable contribution to the STEM literature at the senior high school level. The practical implications include the improvement of learning methods and the development of STEM teaching materials. Meanwhile, the theoretical implications provide a basis for future research to fill the knowledge gaps, especially related to dimensions that have yet to be fully revealed in this study. By strengthening the research methodology and expanding the scope of the study, knowledge about the impact and effectiveness of STEM in senior high school education can be further enriched and thoroughly understood, thus supporting continuous efforts to improve the quality of STEM education at the senior high school level.

5. Conclusion

The research findings underscore the substantial positive impact of integrating STEM education on enhancing student learning outcomes in Senior High School. Contrary to traditional learning methods, STEM interventions demonstrate effectiveness in enhancing various aspects of learning, including knowledge acquisition, creativity, academic achievement, and critical thinking skills. Gender analysis further illuminates the favorable influence of STEM across both gender cohorts, albeit with nuanced variations in impact intensity. Consequently, the integration of STEM into educational practices emerges as a promising avenue for enhancing the overall quality of education at this level. However, the study also underscores the necessity for additional research endeavors to delve deeper into understanding the multifaceted role of gender and other dimensions yet to be fully explored within the domain of STEM education in Senior High School. Such investigations are crucial for refining pedagogical strategies and ensuring equitable educational outcomes for all students.

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