Journal of Ecohumanism
2025
Volume: 4, No: 4, pp. 1592 – 1609
ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v4i4.6895

Effectiveness of Using the Science, Technology, Engineering, and Mathematics (STEM) Approach in Developing Higher-Order Thinking Skills: A Meta-Analysis

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Abstract

This study investigated the effectiveness of the Science, Technology, Engineering, and Mathematics (STEM) approach in developing higher-order thinking skills and examined whether its impact varied according to teaching model, educational stage, field of study, gender, sample size, or learning environment. A meta-analysis was conducted on 35 primary studies published between 2015 and 2025 that employed STEM to enhance higher-order thinking skills among learners across different educational levels. Data were coded using a specially designed coding sheet, and 37 effect sizes were calculated using Hedges' g index to ensure accuracy. Analyses included heterogeneity testing, publication bias assessment, and subgroup comparisons, conducted with Comprehensive Meta-Analysis software (v4) and Microsoft Excel. Results indicated a strong overall effect of STEM on higher-order thinking skills under the random-effects model, with a combined mean effect size of ES = 0.97, SE = 0.085, and a 95% confidence interval of 0.805–1.14. The corresponding percentage value of the combined effect was 33%. Subgroup analysis showed that the STEM approach consistently improved higher-order thinking skills regardless of contextual variables. Accordingly, the study recommends integrating STEM pedagogy into both pre-service and in-service teacher education and training programs to foster higher-order cognitive skills.

Keywords: *STEM Approach, Higher-order Thinking Skills, Meta-analysis, Effect Size.*

Introduction

Education in the 21st century is witnessing radical transformations in its philosophy and methods as a result of rapid developments in the fields of science and technology. This has imposed unprecedented challenges on traditional educational systems, which are no longer capable of meeting the needs of learners in an era based on knowledge, innovation, and artificial intelligence. To prepare new generations to keep pace with the demands of the modern labor market, it has become essential to develop advanced cognitive skills that go beyond memorization and recall to include critical thinking, complex problem-solving, creative thinking, and systemic analysis (Jeon et al., 2021). Focusing on higher-order thinking skills is a fundamental requirement for achieving learners' self-competence and enabling them to flexibly apply their knowledge in diverse contexts, thereby enhancing their ability to interact positively with scientific and technical challenges (Kim & Park, 2022).

Within this framework, the Science, Technology, Engineering, and Mathematics (STEM) approach has emerged as one of the effective educational approaches for addressing these challenges. It is based on the integration of scientific knowledge with technological, engineering, and mathematical applications within active educational practices that rely on projects, design, and realistic problem-solving (Putri et al., 2019). This approach reflects a trend toward meaningful learning, based on the integration of disciplines, and motivates learners to explore real-life issues using interconnected and multidimensional knowledge.

Several studies have confirmed that learning environments based on STEM provide opportunities for developing higher-order thinking skills in their various dimensions. A study by Yilmaz and Yanarates (2022) showed that STEM applications enhance inquiry and innovative thinking skills among middle school students. Hebebci and Usta (2022) explained that the integrative combination of STEM branches raises the levels of critical thinking, problem-solving, and creativity. Yaki (2022) found that the integration of STEM fields contributed to improving critical thinking skills among high school students, especially in inference, interpretation, and argument evaluation. Meanwhile, Evcim and Arslan (2021) demonstrated that designing

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a learning unit on the concepts of force and energy according to the STEM approach produced significant differences in analytical and interpretive thinking among seventh-grade students.

The literature also supported the role of STEM in developing creative thinking through learning environments that provide opportunities for open design, experimentation, and creativity. Putri et al. (2019) showed that using the Challenge-Based Learning (CBL) model within a STEM environment led to an improvement in the fluency, flexibility, and originality of creative thinking. Sirajudin et al. (2021) confirmed that teaching science according to the STEM model provides a fertile environment that stimulates creativity and prompts learners to produce innovative solutions to problems. In the area of problem-solving, Alatas and Yakin (2021) explained that the use of STEM in a physics lesson on "work and energy" raised students' performance on problem-solving indicators, from problem description to solution evaluation. Furthermore, Ince et al. (2018) revealed that the application of STEM in the "earth's crust puzzles" unit for fifth-grade students contributed to raising academic achievement and improving the ability to systematically process problems.

Despite the accumulation of evidence supporting the effectiveness of STEM in developing higher-order thinking skills, the results of the studies were varied. Some showed a high effect on critical thinking (Yaki, 2022; Hebebci & Usta, 2022), while others recorded a moderate or non-significant effect on creative or analytical thinking (Evcim & Arslan, 2021; Putri et al., 2019). This variation is due to differences in experimental designs, measurement tools, duration of application, the type of target group (Yilmaz & Yanarates, 2022), in addition to the diversity of educational activities within the STEM environment, ranging from engineering design to scientific experimentation (Halawa et al., 2021). Some studies also showed that the effect of STEM may differ depending on the targeted thinking style. English (2023) found that systemic thinking skills are more responsive to the application of STEM in environmental science units compared to traditional critical thinking skills.

This variation in results raises questions about the actual value of the STEM approach in developing higher-order thinking patterns, which skills are more responsive to it, and under what educational conditions the best results are achieved. To answer these questions, there is a need to adopt a meta-analysis approach as an advanced statistical tool that allows for the quantitative integration of previous study results, estimation of the true effect size, verification of its statistical significance, and examination of the factors that may explain the variation between the results. This approach also allows for the study of the effect of moderator variables, such as the educational stage, skill type, intervention duration, sample size, and design type, which helps in determining the conditions for effectiveness and when STEM is more influential (Borenstein et al., 2021; Cooper, 2015).

Based on the above, this research seeks to conduct a systematic meta-analysis of experimental studies that dealt with the effect of the STEM approach on developing higher-order thinking skills, with the aim of estimating the total effect size, revealing the differences between studies, and analyzing the factors that may explain these differences. This will enhance the scientific understanding of the effectiveness of STEM in diverse educational contexts. The importance of this research stems from addressing a contemporary educational issue, which is the integration of scientific and technical disciplines in an active and integrated learning environment, and directing this integration toward the development of higher-order thinking, especially in environments that suffer from poor academic performance or the dominance of traditional teaching methods. This makes its results valuable for researchers, practitioners, and decision-makers in the educational field.

Research Questions

1. What is the average effect size of using the Science, Technology, Engineering, and Mathematics (STEM) approach in developing higher-order thinking skills?

2. To what extent does the effectiveness of using the Science, Technology, Engineering, and Mathematics (STEM) approach vary based on: the teaching model used, the educational stage, the field of study, the gender of the study sample, the sample size, and the study environment?

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Purpose of the Research

1. Revealing the effectiveness of the Science, Technology, Engineering, and Mathematics (STEM) approach in developing higher-order thinking skills.

2. Evaluating the extent to which the effectiveness of the Science, Technology, Engineering, and Mathematics (STEM) approach in developing higher-order thinking skills varies according to the type of teaching model used, the educational stage, the field of study, the gender of the study sample, the sample size, and the study environment.

3. Generalizing the results of the current meta-analysis to populations of studies that used the Science, Technology, Engineering, and Mathematics (STEM) approach in developing higher-order thinking skills.

Significance of the Research

1. The results of this research may benefit decision-makers by providing scientific evidence that confirms the effectiveness of the Science, Technology, Engineering, and Mathematics (STEM) approach in developing students' higher-order thinking skills; thus, a decision can be made to adopt the findings of this research.

2. The results of this research hold particular importance for those teaching science and mathematics in understanding the impact of the Science, Technology, Engineering, and Mathematics (STEM) approach on developing students' higher-order thinking skills; consequently, they can adopt this approach at the operational implementation level within classrooms.

3. The results of this research also have special importance for students in understanding the impact of the Science, Technology, Engineering, and Mathematics (STEM) approach on developing higher-order thinking skills; consequently, they can utilize it in appropriate situations.

4. To introduce researchers to the meta-analysis method, which may encourage them to use this method in their future studies.

Research Terms

Meta-analysis

A quantitative statistical method for analyzing the results of previous primary studies that used the Science, Technology, Engineering, and Mathematics (STEM) approach in developing higher-order thinking skills among students. These studies were selected based on specific criteria; their data were coded using a prepared coding sheet, then their effect sizes were calculated using Hedges' g index, and the effect sizes were analyzed using the random-effects model. The aim is to integrate the results of these studies and deduce useful generalizations from the data and findings of these studies, which assist in making a specific decision regarding the adoption of these studies' results.

Science, Technology, Engineering, and Mathematics (STEM) Approach

An educational approach that focuses on integrating these four disciplines together in a holistic manner instead of studying each subject separately. Its goal is to develop students' critical, creative, and problem-solving thinking skills. This approach emphasizes linking theoretical knowledge with its practical application, which helps students understand how science, technology, engineering, and mathematics work together in real life.

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Higher-Order Thinking Skills

A set of specific cognitive processes that can be developed in students using the Science, Technology, Engineering, and Mathematics (STEM) approach. These include critical thinking, creative thinking, and problem-solving skills. These skills help students understand information in depth, use it effectively in new situations, and make informed decisions instead of relying solely on rote learning or superficial recall.

Research Procedures

To determine the effectiveness of the Science, Technology, Engineering, and Mathematics (STEM) approach in developing higher-order thinking skills among learners at different educational stages, a meta-analysis was used. This method is characterized by a series of steps that differ from other quantitative methods. These steps are defining the inclusion criteria necessary to identify the final meta-analysis sample, identifying previous studies related to the research topic, coding the data of the meta-analysis sample studies, calculating the effect sizes for the meta-analysis sample studies, and performing statistical analysis of the data. The following is an explanation of these steps:

Defining the Inclusion Criteria for the Final Sample

Defining inclusion and exclusion criteria is crucial in meta-analysis research because the quality of the meta-analysis depends on the quality of the primary studies included in it. To include rigorous studies in the current meta-analysis, inclusion/exclusion criteria were applied based on a review of (Lipsey & Wilson, 2001; Wahono et al., 2020). These criteria are:

1. The study must be experimental or quasi-experimental and have used the Science, Technology, Engineering, and Mathematics (STEM) approach to develop higher-order thinking skills.
2. The study must have been conducted on students at the primary, middle, secondary, or university level.
3. The study must have been conducted in the field of natural sciences or mathematics.
4. The study must be published in peer-reviewed Arabic or foreign journals, or as published or unpublished master's or doctoral theses.
5. The study must have addressed the development of higher-order thinking skills (critical thinking, creative thinking, problem-solving).
6. The study must have been published between 2015 and 2025.
7. The experimental design of the study must include an experimental group and a control group.
8. The study must include procedures for verifying the psychometric properties of the data collection tools.
9. The studies must include sufficient data to calculate effect size, such as: (sample size, means, standard deviations, f-value, t-value).

Identifying Previous Studies Related to the Research Topic

To compile previous studies that used the Science, Technology, Engineering, and Mathematics (STEM) approach to develop higher-order thinking skills among learners at different educational stages, the following electronic databases were used: Dar Almandumah, ERIC, and Google Scholar. The search was conducted using the following keywords: "STEM" (Integrated STEM approach), (Science, Technology, Engineering, and Mathematics STEM approach), (Effectiveness of STEM on higher-order thinking skills), (STEM and critical thinking), (STEM and creative thinking), (STEM and problem-solving), (STEM curve),

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(STEM direction) in both Arabic and English. Additionally, the reference lists of the quantitative studies collected using the previous methods were utilized. The search, which concluded in June 2025, resulted in 2353 studies.

As a result of applying the aforementioned criteria to the identified set of studies, a total of 35 primary studies that met the inclusion criteria were included. The following diagram illustrates the stages of obtaining the final sample of primary studies for the current meta-analysis:

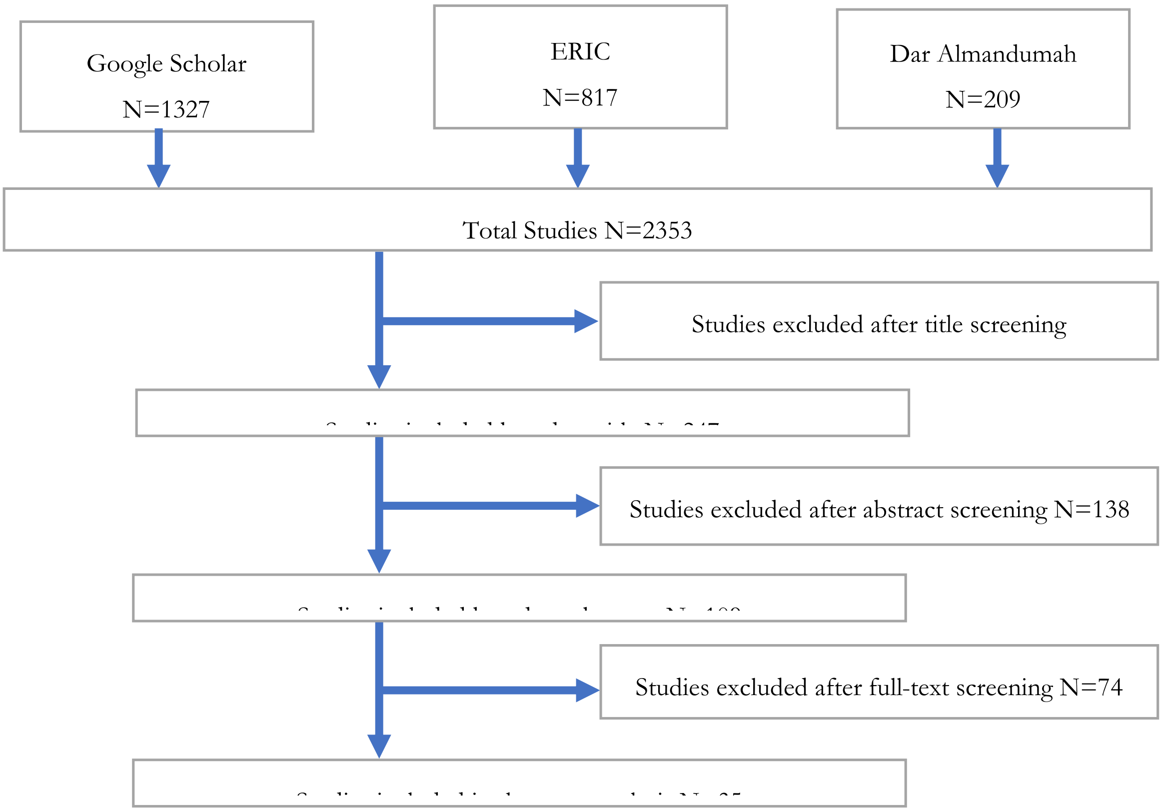

Figure 1. The steps for determining the final meta-analysis sample

Coding the Data of the Meta-Analysis Sample Studies:

To obtain the necessary data to answer the research questions, a coding sheet was prepared. Its preparation followed these steps:

Defining the variables to be coded:

1. Study code: A unique, non-repeatable code for each study, such as: ID01, ID02, ID03.
2. Researcher's name and publication year.
3. Field of study: Natural Sciences and Mathematics.
4. Educational stage: Primary, Middle, Secondary, and University.
5. Study environment: studies conducted in an Arabic environment and studies conducted in a foreign environment.
6. Sample gender: Males, Females, and Males and Females.

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7. Sample size: 60 students or less, and more than 60 students.

8. Statistical data in the study: Including means, standard deviations, sample sizes, and the f-value.

Determining the validity of the coding sheet data:

To ensure the validity of the coding sheet data, its initial form was presented to two faculty members from the College of Education to verify the correctness of its content. Based on their opinions and suggestions, a new element was added to the coding sheet: the nature of the independent variable, which was classified into: STEM approach without a teaching model and STEM approach with a teaching model. The wording of one of the elements was also modified from "Statistical data in the study" to "Statistical data necessary to calculate effect size."

Ensuring the reliability of the coding sheet data:

To ensure the reliability of the coding sheet prepared in this research, 15 studies were randomly selected from the current research sample, and their data were coded using the coding sheet. A colleague was also asked to code the same number of studies after being introduced to the coding sheet and how to use it to code study data. The agreement between the two coders was then calculated using Cohen's Kappa ($\varkappa$) (Sim & Wright, 2005). The value of Cohen's Kappa coefficient was ($\varkappa = 0.89$), which is a high value for agreement between coders according to the indicators of (Landis & Koch, 1977). The following table shows the characteristics of the primary studies in the meta-analysis sample:

Table 1. Characteristics of Primary Studies in the Meta-Analysis Sample

No.	Study Characteristics	Variable	Frequency	Percentage
1	Nature of the Independent Variable	STEM approach without a teaching model	28	80%
		STEM approach with a teaching model	7	20%
2	Educational Stage	Primary Stage	3	8.57%
		Middle Stage	18	51.43%
		Secondary Stage	12	34.3%
		University Stage	2	5.7%
3	Field of Study	Natural Sciences	28	80%
		Mathematics	7	20%
4	Sample Gender	Males	6	17.14%
		Females	4	11.43%
		Males and Females	25	71.43%
5	Sample Size	60 students or less	15	42.86%
		More than 60 students	20	57.14%
6	Study Environment	Arabic Environment	10	28.57%
		Foreign Environment	25	71.43%

The data provided in the previous table highlights the following:

- Regarding the nature of the independent variable, the majority of studies used the STEM approach without a teaching model, with a percentage of (80%).

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- Regarding the educational stage, the majority of studies were conducted on middle school students, with a percentage of (51.43%).

- Regarding the field of study, the majority of studies were conducted in the natural sciences, with a percentage of (80%).

- Regarding sample gender, the majority of studies were conducted on samples including males and females, with a percentage of (71.43%).

- Regarding sample size, the majority of studies were conducted on samples of more than 60 learners, with a percentage of (57.14%).

- Regarding the study environment, the majority of studies were conducted in foreign environments, with a percentage of (71.43%).

Calculating Effect Sizes for the Meta-Analysis Sample Studies

After completing the coding process for the meta-analysis sample data, the effect size for each primary study was calculated separately using the statistical equations appropriate for the nature of the available data in the study, as cited in (Borenstein et al, 2009, p. 26). The formulas are as follows:

(1) $d = \frac{\bar{x}_t - \bar{x}_c}{s_{pooled}}$

Where $\bar{x}_t - \bar{x}_c$ is the difference between the means of the experimental and control groups, and s_{pooled} is the pooled standard deviation of the two groups, which can be calculated using the following equation:

(2) $s_{pooled} = \sqrt{\frac{(n_t-1)s_t^2+(n_c-1)s_c^2}{n_t+n_c-2}}$

Where s_c, s_t are the standard deviations for the experimental and control groups, respectively, and n_t ‘n_c and ‘n_c are the number of individuals in the experimental and control groups, respectively.

To calculate the value of the variance of the effect size, it is obtained from the following equation:

(3) $v_d = \frac{n_1+n_2}{n_1 n_2} + \frac{d^2}{2(n_1+n_2)}$

The value of the standard error of the effect size is calculated from the following equation:

(4) $SE_d = \sqrt{V_d}$

To correct the effect size value for bias, the following equations, cited in (Borenstein et al, 2009, p. 27), were used to adjust the effect size:

(5) $J = 1 - \frac{3}{4df-1}$

Where J is the correction factor, and df refers to the degrees of freedom for two independent groups, which equals $n_1 + n_2 - 2$.

Based on the above, Hedges’ corrected effect size becomes:

(6) $g = Jxd$

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Where g is the Hedges' adjusted effect size, J is the correction factor, and d is Cohen's effect size.

Statistical Analysis and Programs Used in the Analysis

The following programs were used for data analysis:

- Microsoft Excel: It was used for data tabulation by creating a Coding sheet for the easy, accurate, and rapid analysis of the coded primary studies (the current meta-analysis sample). It was also used to prepare the forest plot and funnel plot for publication bias testing.

- The trial version of the Comprehensive Meta-analysis (CMA, v4) software: This software includes a wide range of advanced options for data entry, analysis, and display (Borenstein et al, 2022).

Research Results

This section presents the research results, which will be provided through the following:

1. Results related to the calculation of the combined average effect size of the current meta-analysis sample.

2. Results related to the subgroup analysis.

First: Results Related to the Calculation of the Combined Average Effect Size of the Current Meta-Analysis Sample:

To answer the first research question, which states: "What is the average effect size of using the Science, Technology, Engineering, and Mathematics (STEM) approach in developing higher-order thinking skills?" the following steps were taken:

Determining the type of model used in the current meta-analysis

To determine the type of model to be used, a Heterogeneity test was employed to reveal whether the observed variance in the effect sizes of the meta-analysis sample studies showed significant differences from the expected variance resulting from sampling error. The following table shows the results of the heterogeneity test between the effect sizes of the studies included in the current meta-analysis:

Table 2. Results of the Heterogeneity Test between Effect Sizes in the Current Meta-Analysis Sample

Number of Effect Sizes	**Heterogeneity Indicators**				
37	df	Q	χ2	p	I^2
	36	134.87	55.76	0.000	73.30%

As indicated in table (2), it is clear that the results of the heterogeneity test between the effect sizes in the current meta-analysis sample indicate statistical significance (P=0.000), as the value was (Q=134.87), which is greater than the critical value from the chi-square table, which is (χ2=55.76) with degrees of freedom (df=36) and a confidence level of (α=0.05). The value of the variance ratio indicator for the results was also (I2=73.30%). This shows a large amount of heterogeneity among the results of the studies included in the current meta-analysis, according to the indicators of (Higgins et al, 2003). This indicates that the studies included in the current meta-analysis do not share a common effect size, meaning that the observed variance in the effect sizes is greater than what would be expected from sampling error. Consequently, the results of the studies related to the Science, Technology, Engineering, and Mathematics (STEM) approach included in the current meta-analysis are not homogeneous. Therefore, the appropriate analysis model for these

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studies is the Random Effects Model, which assumes that the combined effect among the results of heterogeneous studies is the average of these effects (Borenstein et al., 2010; Borenstein et al., 2021).

Calculating the combined average effect size of the current meta-analysis sample

Based on the results of the heterogeneity test, the combined average effect size for all studies included in the current meta-analysis was calculated using the random-effects model. The lower and upper limits of the confidence interval, as well as the Z-value, were also calculated to confirm the significance of the combined average effect size, as shown in the following table:

Table 3: Combined Average Effect Size of the Meta-Analysis Sample Using the Random Effects Model

Analysis Model	N	ES	SE	Confidence Interval (95%)		Test of the Mean	
				(LL)	(UL)	Z Value	p
REM	37	0.97	0.0850	0.8050	1.14	11.43	0.000

N: Number of calculated effect sizes, ES: Combined effect size, SE: Standard error of the combined effect size.

As illustrated in table (3), it is clear that the combined average effect size according to the random-effects model was (0.97), with a standard error of (0.085). The confidence interval for the combined average effect size was (lower limit 0.805 - upper limit 1.14) at a 95% confidence level for all studies included in the meta-analysis. This means that the value of the calculated combined average effect size falls between the specified confidence intervals. To reveal the significance of the combined average effect size, the Z-test was used. The Z-value was ($Z=11.43$) and the p-value was ($p<0.001$), which is statistically significant at a significance level of ($\alpha=0.05$). This means that in populations similar to those in this analysis, the average effect size is not exactly zero.

The following figure shows the forest plot of the meta-analysis sample studies, illustrating the effect size of each primary study included in the final meta-analysis sample, its standard error, confidence intervals, and statistical significance.

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Statistics for each study

ID	ES	SE	CI Lower limit	CI Upper limit	Z-Value	p-Value
ID01	0.57	0.26	0.06	1.07	2.20	0.028
ID02	1.75	0.28	1.21	2.29	6.37	0.000
ID03	0.34	0.26	-0.16	0.84	1.32	0.187
ID04	2.08	0.34	1.41	2.75	6.09	0.000
ID05	1.73	0.35	1.06	2.41	5.03	0.000
ID06	2.06	0.32	1.44	2.69	6.46	0.000
ID07	0.83	0.24	0.36	1.30	3.49	0.000
ID08	0.50	0.30	-0.09	1.09	1.65	0.099
ID09	0.96	0.31	0.35	1.58	3.07	0.002
ID10	1.34	0.21	0.93	1.74	6.42	0.000
ID11	0.87	0.27	0.34	1.40	3.20	0.001
ID12	1.13	0.25	0.64	1.62	4.49	0.000
ID13	0.58	0.28	0.03	1.14	2.05	0.040
ID14	1.66	0.28	1.12	2.20	6.04	0.000
ID15	0.87	0.25	0.38	1.35	3.48	0.001
ID16	0.78	0.40	0.01	1.55	1.97	0.048
ID17	0.76	0.31	0.14	1.37	2.41	0.016
ID18	0.06	0.24	-0.40	0.52	0.25	0.799
ID19	0.73	0.21	0.32	1.14	3.45	0.001
ID20	0.60	0.25	0.12	1.08	2.44	0.015
ID21	1.32	0.27	0.80	1.84	4.99	0.000
ID22	0.90	0.23	0.46	1.35	3.98	0.000
ID23	0.94	0.18	0.58	1.30	5.16	0.000
ID24	1.26	0.32	0.63	1.88	3.95	0.000
ID25	1.70	0.27	1.18	2.22	6.39	0.000
ID26	-0.261	0.30	-0.85	0.33	-0.87	0.383
ID27	0.71	0.26	0.21	1.21	2.78	0.005
ID28	1.479	0.29	0.92	2.04	5.17	0.000
ID29	0.84	0.21	0.43	1.25	4.02	0.000
ID30	-0.185	0.30	-0.77	0.40	-0.62	0.533
ID31	0.64	0.35	-0.05	1.34	1.81	0.070
ID32	1.35	0.20	0.97	1.74	6.87	0.000
ID33	0.99	0.30	0.39	1.58	3.25	0.001
ID34	1.48	0.28	0.94	2.03	5.30	0.000
ID35	0.64	0.25	0.15	1.13	2.54	0.011
ID36	1.02	0.32	0.39	1.66	3.16	0.002
ID37	1.20	0.30	0.61	1.79	4.00	0.000
REM	0.97	0.08	0.81	1.14	11.43	0.000

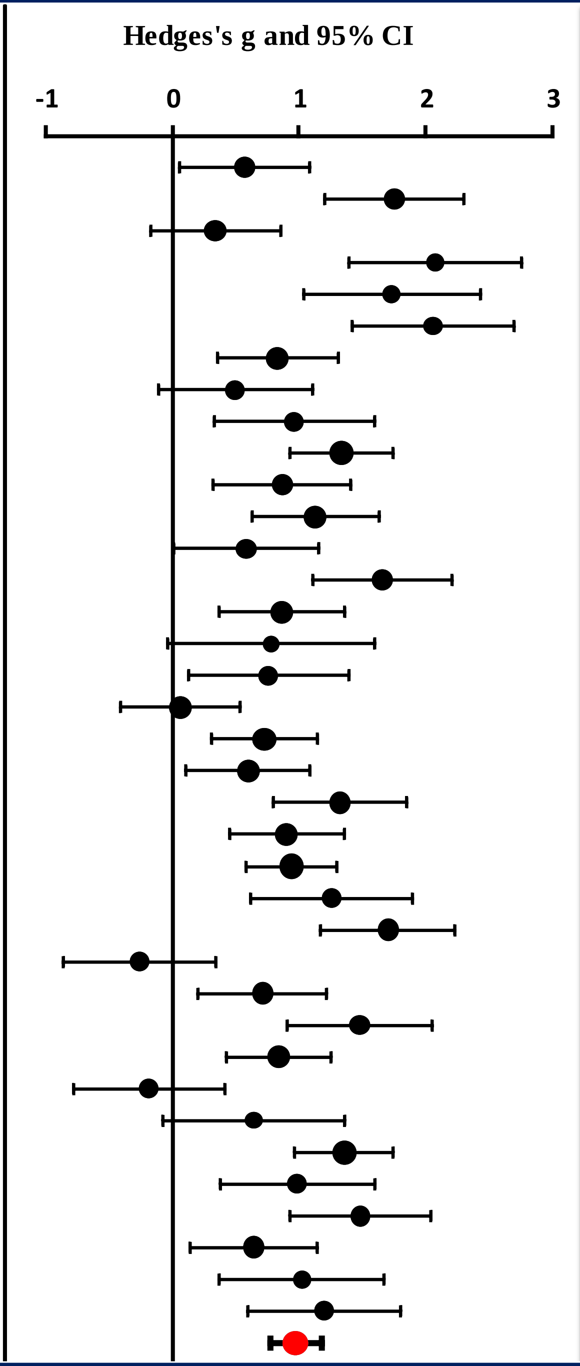

Figure (2): The distribution of effect sizes for the meta-analysis sample around the overall mean effect size (Developed by the researcher via Microsoft Excel).

As illustrated, the solid black circles represent the effect sizes in the primary studies included in the current meta-analysis, while the lines around these circles represent the confidence intervals. The solid red circle at the bottom of the figure represents the combined average effect size according to the random-effects model. According to the forest plot, 35 effect sizes were in the positive direction (in favor of the experimental groups), while only 2 effect sizes were in the negative direction (in favor of the control groups). This means that the effect of the Science, Technology, Engineering, and Mathematics (STEM) approach was in the positive direction, which indicates the effectiveness of using the Science, Technology, Engineering, and Mathematics (STEM) approach in developing higher-order thinking skills at different educational stages.

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DOI: https://doi.org/10.62754/joe.v4i4.6895

Assessing publication bias

To assess publication bias in this research, the visual inspection method of the funnel plot, proposed by (Sterne et al., 2001), was used. This is done through the following figure, which shows the relationship between Hedges' effect size on the x-axis and the standard error of the effect size on the y-axis, in order to scrutinize the appropriateness of the calculated average effect size for this purpose, as well as the extent to which the current meta-analysis sample represents the population of studies that used the Science, Technology, Engineering, and Mathematics (STEM) approach in developing higher-order thinking skills.

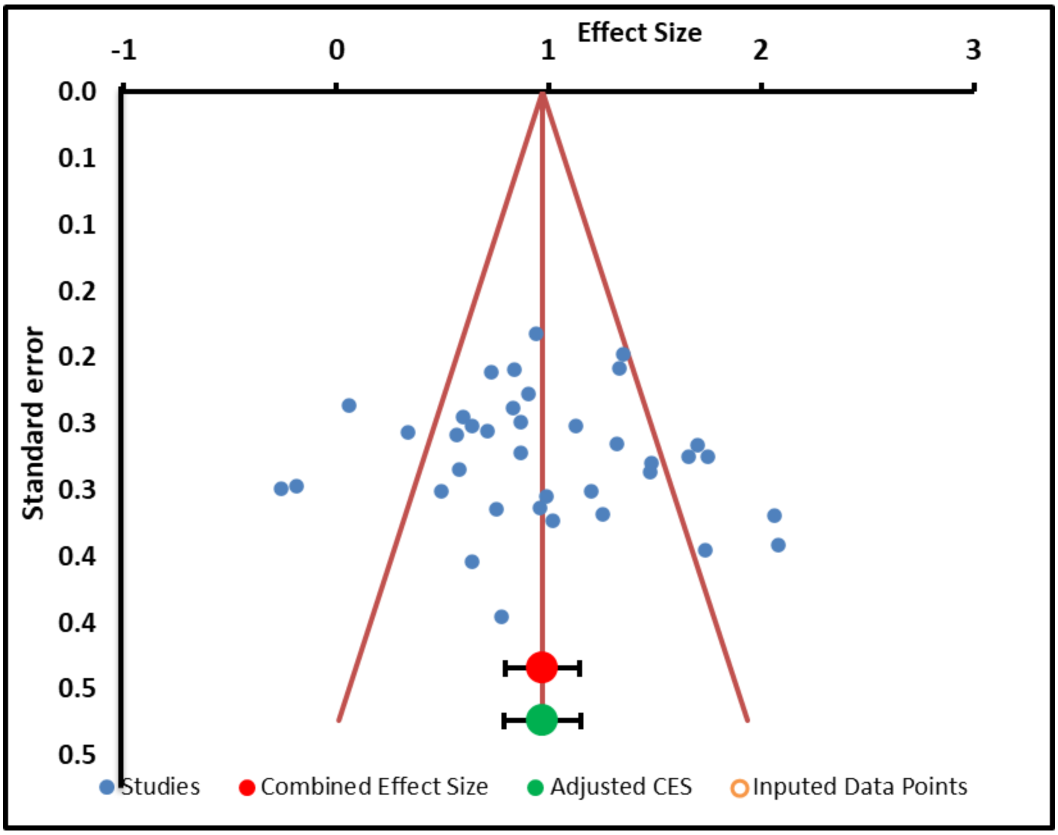

Figure (3): Funnel plot (Developed by the researcher via Microsoft Excel)

According to the funnel plot, the line in the center of the blue circles should be as symmetrical as possible on both sides to eliminate publication bias. Therefore, it can be said that it is completely symmetrical. The reason for this is likely due to the current research including both studies published in peer-reviewed scientific journals and unpublished studies such as master's or doctoral theses in the final meta-analysis sample. This contributed significantly to the complete elimination of the effect of publication bias on the results of the current research.

To further confirm the absence of publication bias, the trim and fill method proposed by Duval and Tweedie (2000) was used. The following table shows the results of applying this method:

Table 4. Results of the Duval & Tweedie (2000) Trim and Fill Test

Average Effect Size (ES)	ES	Confidence Interval (95%)		Number of Missing Studies
		Lower Limit (LL)	Upper Limit (UL)	
Calculated (Observed)	0.97	0.805	1.14	Zero

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ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
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DOI: https://doi.org/10.62754/joe.v4i4.6895

Adjusted	0.97	0.805	1.14	

From the data provided, it is clear that there are no missing studies that need to be added to the current meta-analysis sample. Therefore, the value of the calculated average effect size is equal to the value of the adjusted average effect size, which is (0.97). This is a large value for the effect size according to the classification of (Cohen et al., 2002), which indicates the absence of publication bias in this study. It also means that publication bias cannot explain the significant positive results obtained in this research, which increases confidence in the results of the current research.

To judge the value of the combined average effect size, it was converted to a percentage gain using the table for converting effect sizes to percentage gain, which was developed by Marzano et al. (2001, p. 160). The percentage value for the combined average effect size was (33%). This means that the average scores of students in the experimental groups who were taught using the Science, Technology, Engineering, and Mathematics (STEM) approach were 33 percentage points higher than the average scores of students in the control groups who were taught using traditional strategies. This, in turn, indicates that the Science, Technology, Engineering, and Mathematics (STEM) approach used in the previous studies of the current meta-analysis sample was effective in developing higher-order thinking skills among learners.

Second: Results Related to Subgroup Analysis

In addition to identifying the effectiveness of the Science, Technology, Engineering, and Mathematics (STEM) approach on higher-order thinking skills, this research also answers whether there are specific factors behind this effectiveness. This section addresses the results related to the second research question, which states: "To what extent does the effectiveness of using the Science, Technology, Engineering, and Mathematics (STEM) approach vary based on: the teaching model used, the educational stage, the field of study, the gender of the study sample, the sample size, and the study environment?" Subgroup analysis was used, and the results of these analyses are presented below:

Table 5. Results of Subgroup Analysis

Subgroup	N	ES	SE	Confidence Interval (95%)		Heterogeneity		
				Lower Limit	Upper Limit	Qb	df	P
Teaching Model	37	0.97	0.085	0.805	1.14	0.441	1	0.507
Without teaching model	29	0.942	0.097	0.753	1.131			
With teaching model	8	1.08	0.186	0.717	1.445			
Educational Stage	37	0.95	0.142	0.676	1.233	4.376	3	0.224
Primary	3	0.728	0.298	0.144	1.313			
Middle	19	0.854	0.120	0.619	1.090			
Secondary	13	1.199	0.139	0.926	1.472			
University	2	0.867	0.348	0.185	1.549			
Field of Study	37	0.97	0.086	0.804	1.14	0.236	1	0.627
Natural Sciences	30	0.952	0.095	0.766	1.138			
Mathematics	7	1.059	0.199	0.669	1.450			
Sample Gender	37	1.08	0.18	0.729	1.434	4.713	2	0.095
Males	6	1.032	0.208	0.624	1.440			
Females	4	1.502	0.268	0.976	2.028			
Males and Females	27	0.890	0.096	0.701	1.079			
Sample Size	37	0.97	0.085	0.805	1.14	0.765	1	0.382
60 students or less	17	0.885	0.131	0.629	1.141			

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ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
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DOI: https://doi.org/10.62754/joe.v4i4.6895

More than 60	20	1.036	0.112	0.816	1.256			
Study Environment	37	0.97	0.086	0.803	1.14	0.533	1	0.465
Arabic	10	1.077	0.168	0.748	1.406			
Foreign	27	0.934	0.100	0.738	1.131			

From the results obtained, it is clear that:

Regarding the teaching model used, the value of Qb obtained from the heterogeneity test was (0.441), while the p-value was (p=0.507), which is greater than 0.05. This means there are no differences in the effect size of the Science, Technology, Engineering, and Mathematics (STEM) approach on higher-order thinking skills in terms of the teaching model used (STEM approach without a teaching model, STEM approach with a teaching model).

Regarding the educational stage, the value of Qb was (4.376), while the p-value was (p=0.224), which is greater than 0.05. This means there are no differences in the effect size of the Science, Technology, Engineering, and Mathematics (STEM) approach on higher-order thinking skills in terms of the educational stage (primary, middle, secondary, university).

Regarding the field of study, the value of Qb was (0.236), while the p-value was (p=0.627), which is greater than 0.05. This means there are no differences in the effect size of the Science, Technology, Engineering, and Mathematics (STEM) approach on higher-order thinking skills in the fields of natural sciences and mathematics.

Regarding the sample gender, the value of Qb was (4.713), while the p-value was (p=0.095), which is greater than 0.05. This means there are no differences in the effect size of the Science, Technology, Engineering, and Mathematics (STEM) approach on higher-order thinking skills in terms of sample gender (males, females, and males and females).

Regarding the sample size, the value of Qb was (0.765), while the p-value was (p=0.382), which is greater than 0.05. This means there are no differences in the effect size of the Science, Technology, Engineering, and Mathematics (STEM) approach on higher-order thinking skills in terms of sample size (60 students or less, and more than 60 students).

Regarding the study environment (Arabic, foreign), the value of Qb was (0.533), while the p-value was (p=0.465), which is greater than 0.05. This means there are no differences in the effect size of the Science, Technology, Engineering, and Mathematics (STEM) approach on higher-order thinking skills in terms of the study environment (Arabic, foreign).

Conclusions of the Research

The current research aimed to reveal the effectiveness of using the Science, Technology, Engineering, and Mathematics (STEM) approach in developing learners' higher-order thinking skills through meta-analysis, and to reveal the factors that influence this effectiveness. To achieve this, a meta-analysis was conducted on the results of previous relevant primary studies. A total of 35 primary studies that met the inclusion and exclusion criteria were subjected to the final meta-analysis, and 37 effect sizes were calculated from these studies.

The results of the research's first question, related to calculating the combined average effect size of the experimental studies that used the Science, Technology, Engineering, and Mathematics (STEM) approach, indicated a high effect size in achieving higher-order thinking skills according to the random-effects model, which was (0.97). This value is considered very large according to Cohen's indicators. This was also confirmed by converting it to a percentage using the table for converting effect sizes to percentage gain, developed by Marzano et al. (2001, p. 160). The corresponding value for the effect size was (33%). This means that the average scores of students in the experimental groups who were taught using the Science,

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ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v4i4.6895

Technology, Engineering, and Mathematics (STEM) approach were 33 percentage points higher than the average scores of students in the control groups who used traditional methods. This, in turn, indicates that the Science, Technology, Engineering, and Mathematics (STEM) approach used in these studies was effective in developing learners' higher-order thinking skills.

The researcher attributes this result to the fact that using the Science, Technology, Engineering, and Mathematics (STEM) approach in teaching provides a set of advantages when compared to traditional methods. These advantages include providing an opportunity for active learning, as it is not limited to acquiring knowledge in these disciplines separately, but rather encourages linking them through practical, realistic activities that stimulate the development of higher-order thinking skills. Through collaboration and interaction among students while carrying out activities related to the STEM approach, students learn how to think in a multidimensional way, within an active and social context that requires exchanging ideas, communication, and joint problem analysis. In light of this, higher-order thinking skills such as critical thinking, creative thinking, problem-solving, and decision-making develop through participation in dialogues and discussion circles, which enhances students' ability to deal with real-world challenges (Li et al., 2019).

This result is consistent with the findings of both (Wahono et al., 2020; Zeng et al., 2018), which indicated the effectiveness of the STEM approach on higher-order thinking skills, as well as the study by (Rahmawati et al., 2023), which indicated that the performance of students in the experimental groups who were taught using the STEM approach was better than the performance of students who received traditional instruction in relation to mathematical creative thinking skills. It also aligns with the results of studies by (Azhar et al., 2023; Hiqmah et al., 2023; Putra et al., 2023; Zulyusri et al., 2023), which indicated the superiority of the STEM approach on critical thinking skills. However, it differs from the study by (Monsang & Srikoon, 2021), whose results indicated small effects of the STEM approach on learners' creative thinking skills.

The results of the research's second question, concerning subgroup analysis, indicated that the effect size of the Science, Technology, Engineering, and Mathematics (STEM) approach on higher-order thinking skills did not show statistically significant differences based on the teaching model used. This finding is consistent with the results of the study by (Wahono et al., 2020) but differs from studies by (Rahmawati et al., 2023; Zeng et al., 2018), which indicated that the teaching model used affects thinking skills. Similarly, there were no significant differences based on the educational stage, which aligns with the results of the study by (Zeng et al., 2018) that indicated the STEM approach has similar effects across all educational stages. This, however, differs from the results of studies by (Azhar et al., 2023; Hiqmah et al., 2023; Rahmawati et al., 2023; Putra et al., 2023; Zulyusri et al., 2023), which indicated that the effectiveness of the Science, Technology, Engineering, and Mathematics (STEM) approach varies with different educational stages. The study also found no significant differences based on the field of study, sample gender, sample size, which is consistent with the results of (Hiqmah et al., 2023; Rahmawati et al., 2023; Zulyusri et al., 2023) but differs from the results of the study by (Zeng et al., 2018) which indicated that the use of the STEM approach is more effective with small samples, or based on the study environment (Arabic/foreign).

The researcher attributes the differences between the results of the current research and previous meta-analysis studies to the following reasons:

1. The difference in the scales and tests used to measure higher-order thinking skills in the primary studies included in the current meta-analysis led to different effect size values for these studies.

2. The differences in the number of studies subjected to analysis. For example, the study by (Rahmawati et al., 2023) included 12 studies, while the study by (Zeng et al., 2018) included 11 studies in the final meta-analysis. The study by (Azhar et al., 2023) included 16 studies, the study by (Hiqmah et al., 2023) examined 14 studies, and the study by (Putra et al., 2023) included 13 studies. In contrast, this research examined 35 studies, resulting in 37 effect sizes.

3. The difference in the sample sizes used in the primary studies included in the current meta-analysis, which strongly contributed to the inflated effect size of using the Science, Technology,

ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v4i4.6895

Engineering, and Mathematics (STEM) approach for studies with smaller sample sizes in developing higher-order thinking skills, because effect sizes are biased with small samples.

Recommendations and Suggested Future Research

In light of the results of the current research, the following recommendations can be made:

1. The possibility of utilizing the Science, Technology, Engineering, and Mathematics (STEM) approach to develop many dependent variables in different subjects.

2. Future primary studies and research on the Science, Technology, Engineering, and Mathematics (STEM) approach should include large sample sizes to obtain more accurate estimates of effect sizes.

3. The necessity for future primary studies to focus on examining the effectiveness of the Science, Technology, Engineering, and Mathematics (STEM) approach on samples of students with special needs.

4. Studying the effectiveness of other approaches on higher-order thinking skills in the field of science using the meta-analysis method.

5. Studying the effectiveness of the Science, Technology, Engineering, and Mathematics (STEM) approach on other learning outcomes and understanding the differences according to the nature of the sample (regular students, students with special needs) and the duration of implementation using the meta-analysis method.

6. Since the goal of the current research was to conduct a quantitative analysis to investigate the effectiveness of the Science, Technology, Engineering, and Mathematics (STEM) approach on higher-order thinking skills using the meta-analysis method, it is suggested to conduct a qualitative study that clarifies when and how the Science, Technology, Engineering, and Mathematics (STEM) approach is effective in achieving different thinking skills.

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Appendix

The final meta-analysis sample studies:

The Arabic Studies:

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ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
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Journal of Ecohumanism
2025
Volume: 4, No: 4, pp. 1592 – 1609
ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v4i4.6895
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