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Research Article

The effect of STEM practices on students' attitudes and achievements: A meta-analysis study

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Abstract: This meta-analysis investigates the impact of STEM (Science, Technology, Engineering, and Mathematics) practices on students' academic achievement and attitudes toward STEM subjects. The study used meta-analysis as a research methodology and searched for relevant literature in databases such as EBSCOhost, Scopus, Web of Science, Google Scholar, and ULAKBIM. The keywords used were "STEM," "STEM Education," and "experimental studies on STEM." The search yielded 45 studies, including articles and proceedings papers, of which 22 met the inclusion criteria for the meta-analysis. The Comprehensive meta-analysis (CMA) program was used as a data analysis tool for the data obtained. Effect sizes were calculated, and the values obtained between variables in the studies were presented in the forest plots at a 95 percent confidence interval. As a result, the individual studies included in the analysis are heterogeneous, and the achievement level in the experimental group is approximately 5 points higher than in the control group. So, the achievement level of the students who received STEM education is (on average) 4.89 units higher than those who did not. The results showed that STEM education had a positive and significant impact on students' attitudes toward the course and academic achievement compared to other methods. Therefore, STEM education enhances students' attitudes towards the course and academic achievement.

1. INTRODUCTION

There are numerous areas where development and change can be discussed today. With each passing day, discoveries and innovations emerge that have the potential to revolutionize the way we live and work. The pace of advancement in science and technology is truly remarkable. In this context, scientific research enables the production of scientific knowledge to solve various problems and also contributes to fields such as technology, engineering, and mathematics. Regarding this matter, it is possible to delve into technological advancements by opening a separate parenthesis. In addition to the developments in information and communication technologies since the 2000s, research on nuclear fusion and artificial intelligence is making significant progress today. Significant developments in nuclear fusion studies are expected to provide a solution to the future energy crisis (BBC, 2022). Again, artificial intelligence platforms such as Dall-E and ChatGPT, developed by OpenAI, have been

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widely used quickly, and superior versions of these applications continue to be developed (OpenAI, 2023). These developments draw attention to the importance of science, technology, engineering, and mathematics combined with the acronym STEM. STEM education faces several obstacles, including the need for properly trained and qualified instructors, the need for students to be adequately prepared, the limited integration of STEM disciplines into educational programs, and more credible scientific research in this area. These are significant challenges that must be carefully considered to effectively address the needs of learners and contribute to the advancement of STEM fields (Kiazai *et al*., 2019). For this reason, when promoting a comprehensive approach to STEM education, it is essential to prioritize the quality of both students and teachers. This case means considering not only cognitive aspects but also affective processes. It is crucial to conduct scientific research on this topic to understand how both types of processes impact the learning experience. At this point, attitude and success can be considered remarkable cognitive and affective elements regarding student quality. The objective of this paper was to systematise the existing literature on the relation between STEM practices and attitude and academic achievement of students. Instead of conducting a narrative literature review, a meta-analytic technique was applied. A standard literature review typically comprises a commentary on the findings of previous works. The character of this approach, however, is a qualitative one. It neither allows for a quantitative assessment of the effect of interest nor does it enable its standardisation for different methods applied across studies. The inability to compare estimates obtained by different researchers often leads to a substantial bias in the selection of the literature used in the review. These problems can be overcome by applying a meta-analysis, in other words, by conducting a quantitative literature review. As stated by Matysiak and Vignoli (2007), this methodology, relatively new in the social and educational sciences, has been developed to synthesise, combine, and interpret the abundance of empirical evidence on a specific topic. The purpose of this research is to analyse the effect of STEM practices on students' attitudes and academic achievement by combining and interpreting empirical evidence from related research topics.

1.1. STEM and Reflections on Education

STEM education represents a shift from traditional teaching methods toward a more interdisciplinary and applied approach. By combining scientific inquiry with artistic creativity, STEM aims to cultivate a broad skill set that includes critical thinking, collaboration, and innovation. Çepni and Çil (2009) state that individuals can gain high-level scientific process skills from school age. According to the data obtained in this study, it was determined that STEM practices caused improvement in students' scientific process skills. The fact that STEM practices have caused changes in scientific process skills demonstrates that high-level developments can be achieved through the development of teaching processes that integrate STEM. According to Yıldırım (2016), "STEM education is a contemporary approach that aims to use an integrative approach while educating individuals and teaching them the necessary skills in daily life and scientific process that can meet the needs by equipping them with 21st-century skills. STEM education is recognized as an integrative approach that enables individuals to connect their daily experiences with the course material. This education is crucial for individuals to stay informed about global developments, propose innovative solutions, and adapt to emerging trends. In this respect, STEM education has a structure that can be applied in each stage of education (Aydagül & Terzioğlu, 2014; Breiner *et al*., 2012; Bybee, 2010). STEM education is essential for developing critical thinking, problem-solving skills, and preparing students for a future in an increasingly technology-driven world. Reflecting on STEM practices in education involves not only understanding its core components but also considering how these practices can be effectively implemented and evaluated to enhance learning outcomes (Belland *et al*., 2017; Lestari *et al*., 2018).

1.2. The Relationship Between STEM Education and Student Achievement

Research consistently shows that students involved in STEM programs perform better academically, especially in math and science. For instance, Özkan and Doğan (2022) found that seventh-grade students engaged in STEM activities demonstrated significantly higher academic performance and improved attitudes toward science. Scientific process skills are skills that can be developed through formal education processes in schools and can be influenced by the teaching methods and techniques employed in these processes. The integration of arts into STEM education nurtures creativity and problem-solving abilities. Henriksen (2014) emphasizes that excellent STEM teachers often incorporate creative strategies from the arts to enhance learning outcomes. Yigit and Bagci (2024) support this with a meta-analysis showing that STEM education significantly improves student creativity. STEM education utilizes hands-on, inquiry-based learning to enhance student engagement. Beers (2011) argues that 21st-century skills, such as communication and collaboration, are best developed through STEM learning environments. Yilmaz and Yilmaz (2024) found that gamified STEM activities increase both motivation and academic performance. At the same time, STEM education prepares students for real-world challenges by fostering critical thinking and collaboration. Marshall and Horton (2011) show that inquiry-based instruction, a core component of STEM, leads to higher-order thinking skills. Yakman (2008) presents a model for integrative education that aligns well with contemporary workforce demands.

1.3. The Relationship Between STEM Education and Student Attitude

Student attitude can be broadly defined as a learner's internal disposition toward education, including their emotional responses, cognitive beliefs, and behavioral intentions (Fraser, 1998). It is often reflected in students' enthusiasm for learning, willingness to engage in academic tasks, and their resilience in the face of challenges. Student attitude is a multifaceted construct encompassing learners' emotions, beliefs, and predispositions toward their academic environment and learning processes. As an integral component of student behavior, attitude has a significant influence on motivation, classroom engagement, and ultimately, academic success (Ajzen, 1991). Research consistently demonstrates a strong correlation between positive student attitudes and higher academic achievement (Pintrich & De Groot, 1990). Students with a growth mindset—those who believe that intelligence can be developed—tend to embrace challenges and persist in the face of setbacks (Dweck, 2006). Conversely, students with negative attitudes often experience lower motivation, increased absenteeism, and reduced performance. A constructive attitude not only enhances academic scores but also fosters critical thinking, creativity, and collaborative skills. Furthermore, in recent years, studies have shown that teaching processes with STEM practices can positively affect students' learning journeys, such as inner motivation and positive attitudes for classroom achievement (Bedar & Al-Shboul, 2020; Belland, *et al*., 2017; Cunningham & Hester, 2007; Lestari, *et al*., 2018; Mousoulides, 2013). Reflecting on STEM practices in education reveals that, while they offer transformative potential for student learning, they also present unique challenges. It requires teachers to be flexible, creative, and supportive in their approach. Additionally, STEM education should focus not only on knowledge acquisition, but also on developing lifelong skills that students can apply to any career or area of their life. By integrating hands-on learning, problem-solving, and interdisciplinary approaches, STEM education can better prepare students for the complexities of the modern world, fostering not just technical skills but also collaboration, critical thinking, and adaptability (Sanders, 2009; Xie *et al*., 2015). STEM practices have a direct impact on student success and attitude by fostering a deeper, more engaging learning experience. Hands-on activities, inquiry-based learning, problem-solving, technology integration, and collaboration all play key roles in developing not only students' academic abilities but also their mindset and motivation. When STEM practices are implemented thoughtfully, they can help students succeed academically and develop positive attitudes toward learning, challenges, and their potential future in STEM fields (Madden *et al*, 2016).

1.4. The Significance and Challenges of STEM Education

Individuals may require some level of STEM education to understand the significance of scientific and technological advancements and their impact on human life, as well as to comprehend issues like global climate change, epidemics, environmental pollution, and water scarcity (Marrero, 2014). Furthermore, understanding STEM is crucial for individuals to make informed decisions that positively impact themselves, their families, and their communities (Tate *et al*., 2012). In the context of contemporary society, the issue of sustainability is arguably one of the most pertinent. In this context, STEM education assumes a critical role in generating competent individuals who can proffer innovative solutions to this challenge. Ensuring that all students are equipped with an understanding and exposure to the fields of STEM is a crucial step towards fostering individual development and making a significant contribution to the global community. This effort can lead to an increase in the number of professionals in diverse fields such as engineering, medicine, science, and mathematics, which can positively impact the world at large (Blotnicky *et al*., 2018). Thus, integrating all members of society into STEM education is paramount in sharing diversified research and knowledge, ultimately leading to an enhanced innovation process fuelled by a broad range of perspectives and data (Marrero, 2014).

Initially, STEM education generated enthusiasm across a wide range of fields and became a topic of interest, from botany to industries producing consumer goods (Bybee, 2013). However, educators often encounter various challenges when teaching STEM subjects (Ejiwale, 2013; Martín-Páez *et al*., 2019):

- Deficiencies in training qualified STEM teachers,
- Problems related to student readiness and motivation,
- Difficulty integrating fields such as technology and engineering into schools and curricula,
- Insufficient content for STEM education,
- Problems related to measurement and evaluation that are appropriate for STEM education,
- Laboratory and teaching environment problems for STEM education,
- Challenges to simplify the technical and complex issues concerning STEM,
- Limitations in research on STEM education,
- Difficulty converting the STEM concept from a slogan to an educational concept.

When examining competencies related to STEM education, researchers typically approach the subject in two different ways. Some studies examine students' attitudes and achievements towards STEM education in real-world settings (Beatty, 2011; Hackman, 2021; National Research Council, 2011; Vennix *et al*., 2018). These studies primarily aim to provide descriptive insights. Other studies, on the other hand, employ experimental research methods to analyze more complex data and examine the impact of STEM education on student attitudes and achievement levels (Baran *et al*., 2019; McClain, 2015; Tolliver, 2016; Wang *et al*., 2022).

When executed efficiently, experimental research yields valid and reliable data on the variables being studied. However, due to its nature, this type of research is typically conducted on a small sample size in the educational field (Creswell, 2015). The issue at hand is the question of whether the results of these studies can be applied to the broader universe. To address this, researchers employ methods such as meta-synthesis or content analysis for qualitative data and meta-analysis for quantitative data to combine findings from similar studies and produce more universally applicable results (Cohen *et al*., 2007). Since the related studies on STEM education are primarily experimental, meta-analysis can be considered a fundamental research type from which we can benefit.

The literature in this field includes relevant investigations. Some of these studies employed meta-synthesis and content analysis to examine existing research on STEM education (Kanadlı, 2019; Kaya, 2020; Ormancı, 2020; Yıldırım, 2016). A limited number of studies, utilizing meta-analysis as their approach, specifically focused on analyzing the different effects of certain variables in experimental studies related to STEM education (Ayverdi & Aydın, 2020; Değer & Yapıcı, 2022; Kazu & Kurtoğlu Yalçın, 2021; Ulum, 2022). According to Olasehinde and Olatoye (2014), attitudes significantly influence academic performance across various subjects. However, no studies have been found that deal with variables such as attitude and achievement, which are essential cognitive and affective processes in STEM education, in an integrated way. In other words, various studies have assessed the effects of diverse integrated STEM studies. By compiling the results in the relevant literature, it is possible to draw a broad conclusion about the impact of different integrated STEM studies on student achievement and attitudes. From this perspective, it is considered essential to conduct a meta-analysis study that examines the impact of STEM education on students' attitudes and achievement levels in a comprehensive manner.

When examining the literature, it becomes apparent that STEM practices have an impact on student achievement and attitude in various areas. These can be summarized in Table 1 below.

Table 1. *The effects of STEM practices on students' achievement and attitude in the literature.*

STEM and Student Achievement		STEM and Student Attitude	
Steps	Impacts	Steps	Impacts
Active Learning Approaches	It helps students develop critical thinking and problem-solving skills.	Fostering a Growth Mindset	This can foster a **growth mindset**, where students believe that their abilities can be developed through effort and perseverance.
Integration of Technology and Tools	This helps students understand complex scientific, mathematical, and engineering concepts in a more interactive way.	Promoting Curiosity and Intrinsic Motivation	It fosters intrinsic motivation, such as natural curiosity and interest in the subject matter.
Collaboration and Teamwork	It helps students learn from one another, refine their ideas, and develop teamwork skills.	Increased Self-Confidence	It can significantly boost students' **self-confidence** in their abilities, especially when they overcome challenges and see tangible results.
Interdisciplinary Approach	This approach helps students see the relevance of what they are learning	Equity and Inclusivity	It leads to greater diversity among future STEM professionals, regardless of their background.
		Real-World Relevance	It helps them contribute to solving global issues (e.g., climate change, technological innovation)

According to Table 1, STEM practices offer a powerful means of fostering higher-order thinking, collaborative problem-solving, and technological fluency. When implemented thoughtfully, these methods can improve both student achievement and attitude, making learning more meaningful and engaging. This interdisciplinary approach supports the broader goal of preparing students for the complexities of modern life and work.

1.5. Aim of the Study

This research aims to conduct a meta-analysis on the effect of STEM education on students' attitudes and achievement levels. In the present research, individual studies that discussed the relationship between STEM education and attitudes and academic achievement of students in the industry will be examined via meta-analysis methodology. The hypothesis on the relationship between the variables and on the intensity of the relationship in question will be tested. For this purpose, the following research questions were included in the study:

- What are the achievement levels of students who attended STEM education according to studies analysed?

• What are the attitudes of students who attended STEM education according to studies analysed?

2. METHOD

A meta-analysis was employed as the research methodology for this study. Meta-analysis is the process of systematically collecting, synthesizing, and analysing the findings of multiple studies on a specific subject (Shelby & Vaske, 2008). Meta-analysis is a method of combining the results of independent, multiple studies and performing statistical analysis of the obtained research findings (Parker *et al*., 2013), explaining the results of each study with the help of a numerical index, and then combining those estimates throughout the studies to reach a summary (Quintana & Minami, 2006). By researching the sample selected through meta-analysis, researchers attempt to make predictions and generalizations about the population, acknowledging a certain probability of error. Meta-analysis provides a general effect size (*r*-value) and confidence interval on the cumulative evidence derived from the combination of two or more studies (Hedges & Pigott, 2004). The fixed-effect or randomized-effect model is used to analyse the studies in a meta-analysis. Suppose the results of individual studies in the meta-analysis are homogeneous. In that case, the fixed-effect model is preferred, but if the results are heterogeneous, then the random-effects model is selected to analyse the data. (Celiker *et al*., 2019).

The methodological process discussed regarding the meta-analysis process is presented below under 11 subheadings as eligibility criteria, information sources, search strategy, selection process, data collection process, data items, study risk of bias assessment, effect measures, synthesis methods, reporting bias assessment, and certainty assessment (Page *et al*., 2021).

2.1. Eligibility Criteria

Meta-analysis studies differ from most studies, and it is an analysis method that analyzes the results of individual studies conducted on the subject of interest. In the words of Glass (1976), the meta-analysis method, which is the synthesis of individual studies related to the researched topic and the presentation of an analysis from the beginning, aims to show the big picture. Therefore, in this study, the results of individual studies conducted on the researched topic are used. In addition to these, all of the individual studies previously conducted on the subject under consideration constitute the universe and therefore the sample of the meta-analysis (Tarım, 2003). Those meeting the inclusion criteria below were included in the meta-analysis:

- Full-text articles that examine the relationship between student achievement/attitude and STEM education.
- Publications subjected to peer review and have been published in academic journals.
- Studies with correlation coefficients to get the standardized effect size in the meta-analysis studies.

2.2. Information Sources

A literature search was made in EBSCOhost, Scopus, Web of Science, Google Scholar, and ULAKBIM (Turkish Academic Network and Information Center) databases using the keywords “STEM,” “STEM Education,” and “experimental studies on STEM." The databases preferred in the study are widely accepted indexes, especially in the field of educational sciences. However, since academic publications that passed the review process were preferred, theses were not included in the study. For the selection of studies, criterion sampling was employed in this study, rather than the traditional purposive sampling. In purposive sampling, researchers select samples that they believe will meet their information needs, depending on the study's purpose (Fraenkel & Wallen, 2009). Criterion sampling is the method of using people, events, or objects with certain predetermined qualities in a research sample selection

(Büyüköztürk *et al*., 2015). At the end of the literature search, 45 studies were collected, comprising articles and proceedings papers.

2.3. Search Strategy

The 22 studies included in the analysis (Appendix A) generally examined the effect of STEM education on student achievement and attitude. These studies were included in the analysis process as they provided experimental data as a criterion.

2.4. Selection Process

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart is a key component of systematic review methodology, providing a transparent and structured way to report the process of study selection. The flowchart outlines the different stages of the study selection process, as outlined by Moher *et al*. (2009). The study screening process of the research is presented in a flowchart of the meta-analysis process (see, Figure 1).

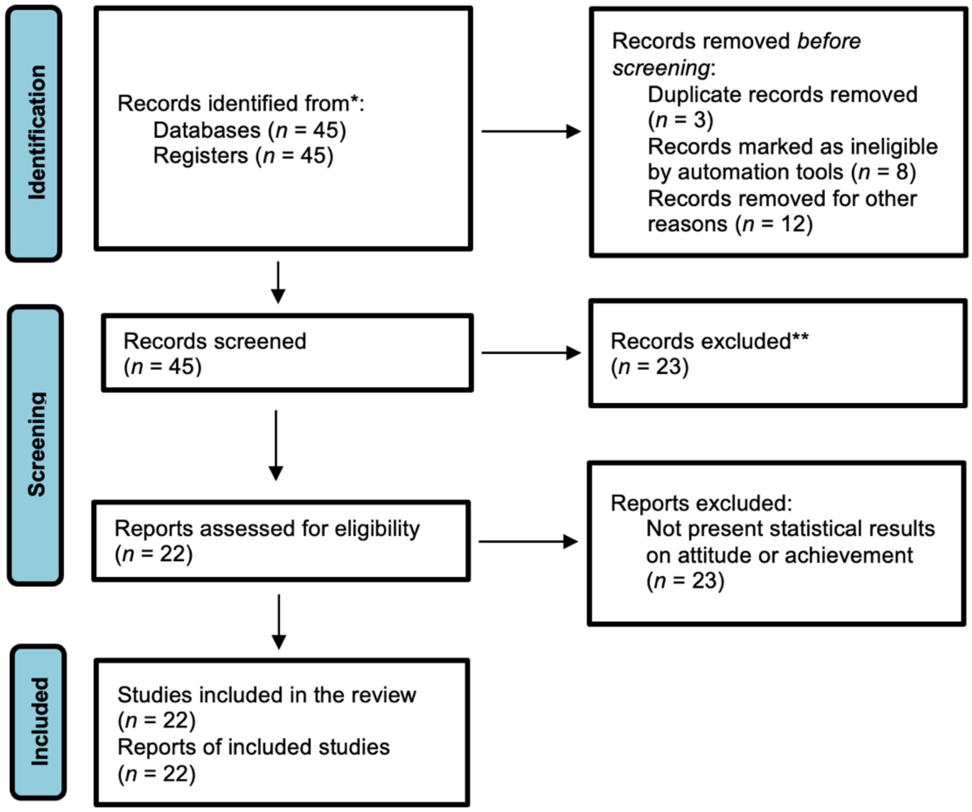

Figure 1. *PRISMA flowchart of the study screening process* (*Adapted from Moher et al. (2009).*

As seen in the flowchart:

While 45 records were initially identified through database searches. 23 of these records were excluded based on the title/abstract screening. Then, 22 full-text articles were assessed for eligibility, and 23 were excluded. Ultimately, 22 studies were included in the meta-analysis.

2.5. Data Collection Process

Two researchers coded the titles, author(s) of the study, publication years, publication types, sampling size, correlation coefficients, populations, and scales. After the results were obtained, the Kappa statistic was used for inter-coder reliability. Kappa statistic, which is frequently used to determine inter-rater reliability, was developed to determine the degree of agreement between two raters scoring at the classification level. Kappa statistics take values between -1 and +1. It is stated that the closer the value ranges for the interpretation of Kappa Statistics are to +1, the higher the inter-coder reliability. The result obtained according to the inter-coder scoring was determined as .91, and this was interpreted as the inter-coder reliability index is very high (Landis & Koch, 1977)

2.6. Data Items

In meta-analysis, data item selection refers to the process of choosing specific pieces of data from individual studies that will be combined and analysed to assess the overall effect of an intervention. Careful selection of data items is crucial to ensure that the meta-analysis yields reliable and valid conclusions. Therefore, the research questions determine which data items are relevant before selecting them. From the eligible studies, researchers include specific data items for meta-analysis. The key data items include: Effect sizes (e.g., mean difference, odds ratio, risk ratio, hazard ratio, standardized mean difference).

- Sample sizes for experimental and control groups.
- Outcome measures (e.g., means, standard deviations, confidence intervals).
- *p*-values or other statistical values indicating significance.

2.7. Study Risk of Bias Assessment

Risk of bias assessment is an essential component of meta-analysis because it helps determine the reliability and validity of the studies included. Bias refers to any systematic error that can distort the true effect of an intervention or treatment. Identifying and evaluating the risk of bias within the individual studies is crucial for drawing accurate conclusions from the meta-analysis. In this study, researchers used statistical techniques to adjust for bias in meta-analysis, such as funnel plot analysis to check for publication bias. Funnel plot, Classic fail-safe *N*, Begg and Mazumdar Rank Correlation, Egger regression, and Duval Tweedie's trim-and-fill methods were used to determine whether the studies included in the meta-analysis caused any publication bias.

2.8. Effect Measures

In meta-analysis, effect measures (or effect sizes) are used to quantify the magnitude of the effect of an intervention or treatment across different studies. These measures summarize the relationship between an intervention and an outcome, making it possible to combine results from different studies in a meaningful way. The random-effects model is used to combine the results of different studies, accounting for the fact that the true effect size might differ from study to study due to differences in study populations, interventions, and methodologies. This model assumes that the effect sizes estimated in each study are not identical but rather vary around a central true effect. Therefore, the data must be converted into a standard unit of measurement to statistically combine the individual research findings and reach a consensus in meta-analysis studies. The effect size index in a correlation study is calculated as the correlation between the independent variable classification and the individual scores of the dependent variable (Neely *et al*., 2010). The effect sizes obtained from the test statistics of individual studies were standardized and tested to determine the strength of the relations in the context of the specified hypothesis in this study. Fisher's *Z* formula was used to calculate the effect size; also, correlation-based effect size classification was used to interpret the effect size obtained (Cohen, 2007):

- Effect size < 0.10 : very low level
- $0.10 \leq$ effect size < 0.30 : low level
- $0.30 \leq$ effect size < 0.50 : medium level
- $0.50 \leq$ effect size < 0.80 : strong level
- Effect size ≥ 0.80 : very strong level

2.9. Synthesis Methods

In meta-analysis, synthesis methods refer to the statistical techniques used to combine results from multiple studies and draw a comprehensive conclusion. These methods allow researchers to integrate findings from diverse studies, quantify the overall effect size, and account for study differences or heterogeneity. Statistical heterogeneity is related to the variability in effect sizes in individual studies. It is known that only if there is real heterogeneity between the estimated effect sizes of several studies, as meta-analyzed, is it clearly visible (Huedo-Medina *et al*., 2006). In meta-analysis, heterogeneity exists when the variance between individual studies is significantly increased. Heterogeneity tests and heterogeneity measures are not directly related to the variance value between individual studies, but rather to the increased variance value due to heterogeneity (Mittlböck & Heinzl, 2006; Sutton *et al*., 2000). In this research, Cochran's Q statistic is used for the heterogeneity test. It is the most common and straightforward approach used to assess whether there is real heterogeneity among the individual studies included in the meta-analysis (Cochran, 1954).

2.10. Reporting Bias Assessment

There are several methods used to assess the potential for reporting bias in a meta-analysis. The main strategies involve visual inspection of data and statistical tests to determine whether smaller studies or studies with certain characteristics (e.g., larger effects) are more likely to be published. In this research, a funnel plot was used to assess publication bias by plotting the effect size estimates from individual studies. Egger's test was used to formally assess funnel plot asymmetry. This test was used because it can help confirm whether the asymmetry is statistically significant.

2.11. Certainty Assessment

Certainty assessment (also referred to as "quality of evidence" or "confidence in estimates") in meta-analysis is a process that evaluates the degree of confidence one can have in the overall findings of the meta-analysis. This is crucial because, while meta-analysis aggregates the results of multiple studies, the strength of the conclusions depends on factors such as the study designs, consistency of results, risk of bias, and other methodological considerations. Six steps were followed in this research to assess certainty.

Step 1 (Evaluate risk of bias): This step evaluates the extent to which the individual studies included in the meta-analysis were well-designed and free from systematic errors

Step 2 (Assess heterogeneity): Heterogeneity is typically assessed in this step. Inconsistency measures how much the study results vary across different studies. If studies report conflicting findings or the results are highly variable, the certainty of the overall evidence is reduced.

Step 3 (Check for Indirectness): Indirectness refers to whether the evidence is directly applicable to the question being asked in the meta-analysis. It involves the degree to which the population, intervention, comparator, and outcomes in the studies match the research question.

Step 4 (Assess Imprecision): Imprecision refers to the extent to which the estimates of effect sizes are precise. This is typically evaluated by looking at the confidence intervals of the pooled effect estimate.

Step 5 (Publication bias): Publication bias refers to the tendency for studies with positive or significant findings to be more likely to be published than those with null or negative results. This can skew the results of a meta-analysis.

Step 6 (Final judgement): After considering the above factors, a final certainty rating is assigned to the overall body of evidence. The grade system typically rates the evidence as high, moderate, low, or very low certainty

3. RESULTS

3.1. The Effect of STEM Education on Student Achievement

The effect of STEM Education on student achievement is given in Table 2 and Figure 2.

Table 2. *Model statistics for each study.*

Study	Difference in means	Standard error	Variance	Lower limit	Upper limit	*z*-value	*p*-value
Study (1)	2.68	1.30	1.70	0.12	5.24	2.05	.04
Study (2)	4.75	0.98	0.96	2.83	6.67	4.85	.00
Study (3)	8.04	3.22	10.38	1.73	14.37	2.50	.01
Study (4)	2.19	0.82	0.66	0.57	3.81	2.66	.01
Study (5)	12.00	0.68	0.47	10.67	13.33	17.63	.00
Study (6)	4.89	0.73	0.54	3.45	6.33	6.68	.00
Study (7)	1.77	0.79	0.62	0.22	3.32	2.24	.03
Study (8)	10.35	6.51	42.40	-2.41	23.11	1.59	.11
Study (9)	15.27	5.15	26.57	5.17	25.37	2.96	.00
Study (10)	4.01	2.20	4.85	-0.30	8.32	1.82	.07
Study (11)	0.34	1.53	2.35	-2.66	3.34	0.22	.82
Study (12)	6.22	2.61	6.84	1.10	11.34	2.37	.02
Study (13)	4.48	0.48	0.23	3.55	5.41	9.40	.00
Study (14)	3.50	0.66	0.43	2.22	4.78	5.31	.00
Study (15)	5.54	1.34	1.81	2.91	8.18	4.12	.00
Fixed	4.89	0.22	0.05	4.46	5.32	22.26	.00
Random	4.89	0.88	0.77	3.17	6.61	5.57	.00

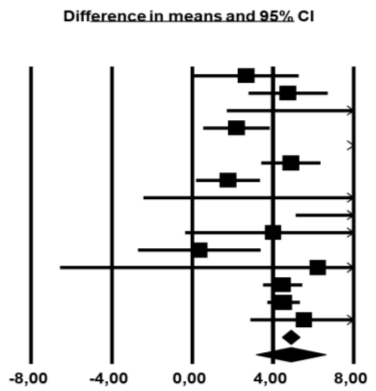

Figure 2. *Forest plot of experimental and control groups.*

As seen in Table 2 and Figure 2, the combined effect according to the fixed and random effects model is 4.89. In other words, the achievement level in the experimental group is approximately 5 points higher than in the control group. In other words, the achievement level of the students who received STEM education is (on average) 4.89 units higher than those who did not. According to the data in Table 3, the individual studies included in the analysis are heterogeneous Q (154.880, $p < .05$) and I^2 (90.96), so the random effects model will be preferred in the meta-analysis.

Table 3. *Variation in effect size.*

Heterogeneity			Tau-squared			
df (*Q*)	*p*-value	I-squared	Tau Squared	Standard Error	Variance	Tau
14	.000	90.961	8.188	5.032	25.317	2.862

According to the random effects model in Table 4, the summary effect has a *z* value of 5.57 and a *p* value of .000 ($p < .05$). Thus, the null hypothesis claiming that there was no real mean difference between the experimental and control groups was rejected, and it was concluded that the achievement levels of the students who received STEM education created a statistically significant difference compared to those who did not.

Table 4. *Average effect size.*

Model	Number of Studies	Effect size and 95% confidence interval: Point Estimate	Standard Error	Variance	Lower Limit	Upper Limit	Test of null (2-Tail): *z*-value	*p*-value
Fixed	15	4.889	0.220	0.048	4.459	5.319	22.261	.000
Random	15	4.890	0.877	0.770	3.171	6.610	5.574	.000

3.2. Publication Bias Tests

Funnel plot, Classic fail-safe *N*, Begg and Mazumdar Rank Correlation, Egger regression, and Duval Tweedie's trim-and-fill publication bias tests were performed to test whether the individual studies included in the meta-analysis carried publication bias.

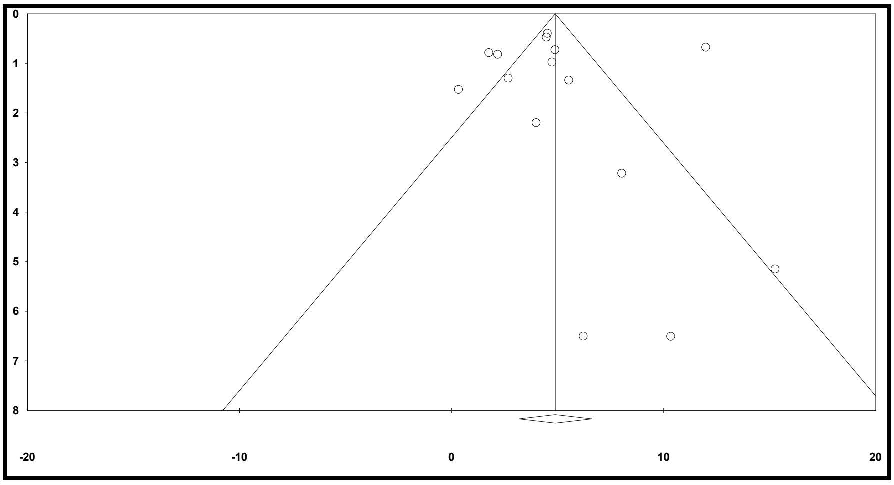

Figure 3. *Funnel scatter plot.*

Figure 3 shows the funnel plot test results of the individual studies included in the meta-analysis. In order to avoid publication bias, the circles representing each study are expected to be symmetrical to each other and gather at the top of the graph. An essential advantage of this method is that it provides the best unbiased effect size value. When Figure 3 is analysed, it is observed that 2 of the individual studies are located at the bottom of the graph, which may lead to publication bias. In order to make a general inference for publication bias, other publication bias tests need to be performed (see, Table 5).

Table 5. *Publication bias tests.*

Classic Fail-Safe *N*	Egger regression (*p*-value 2-tailed)	Kendall *Tau b*	Duval Tweedie's trim and fill (random effect): Studies trimmed (to the right)	SMD observed (adjusted)
1297	.92	0.28	0	4.88-4.88

Classic fail-safe *N* refers to the number of new studies required to convert the overall probability value from the pooled test to a value greater than the specified critical value for statistical significance. That is, Classic fail-safe N calculates the number of missing studies, i.e., studies excluded in a meta-analysis. According to the Classic fail-safe *N* test results, the number of studies required for the *p*-value to be greater than .05 is calculated. Accordingly, it can be stated that to address publication bias in this meta-analysis study ($p < .05$), 1297 more studies should be added to the analysis unit. Since it is not possible to reach this number of studies in this research area, this result is proof that there is no publication bias.

The Egger regression test, which determines the asymmetry in the funnel plot, indicates that there is no publication bias when the *p*-value is above .05. According to the Egger regression test results, the *p*-value was above .05 (.92), indicating that our meta-analysis study does not carry publication bias.

A formal test for publication bias can be performed by examining the correlation between the effect estimates and their variances. The Begg and Mazumdar rank correlation test is a popular technique for assessing the likelihood of publication bias, which complements the funnel plot. In this method, the Kendall tau b coefficient is calculated. Without publication bias, this coefficient is expected to be close to 1, and the two-tailed *p*-value is not expected to make a significant difference. When the statistical values obtained as a result of the bias test are analysed (*Tau b* = 0.28; *p*-value (two-tailed) .13, $p > .05$), the evidence that there is no publication bias in the study is supported.

Duval Tweedie's trim and fill method is also used to estimate the possible number of missing studies in the meta-analysis and their impact on the overall findings. According to the adjusted *SMD* results of the truncated studies, no differences in the size and direction of the variables that could lead to publication bias were detected.

When the evidence obtained from the publication bias tests is evaluated in general, it can be stated that the meta-analysis study does not have an analysis unit that may lead to publication bias; in other words, the study unit included in the analysis does not carry publication bias.

3.3. The Effect of STEM Education on Student Attitudes

The effect of STEM Education on student attitudes is given in Table 6. As seen in the table and Figure 4, the combined effect is 0.72 according to the fixed-effects model and 7.28 according to the random-effects model.

Table 6. *Model statistics for each study.*

Study	Difference in means	Standard error	Variance	Lower limit	Upper limit	*z*-value	*p*-value
Study (1)	28.00	3.37	11.38	21.39	34.61	8.30	.00
Study (2)	6.13	1.81	3.27	2.59	9.67	3.39	.00
Study (3)	0.51	0.16	0.03	0.19	0.83	3.16	.00
Study (4)	1.73	7.08	50.06	-12.14	15.60	0.24	.81
Study (5)	7.44	2.69	7.23	2.17	12.71	2.77	.01
Study (6)	2.46	6.96	48.44	-11.18	16.10	0.35	.72
Study (7)	3.84	1.00	1.00	1.88	5.80	3.85	.00
Fixed	0.72	0.16	0.03	0.41	1.03	4.57	.00
Random	7.28	2.35	5.52	2.67	11.88	3.10	.00

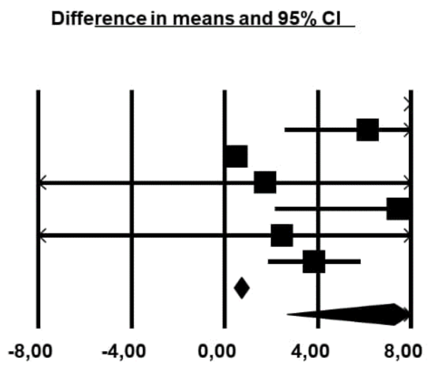

Figure 4. *Forest plot of experimental and control groups.*

According to the data in Table 7, the individual studies included in the analysis are heterogeneous. According to Q (92.109, $p < .05$) and I^2 (93.48) values, the random effects model will be preferred in meta-analysis.

Table 7. *Variation in effect size.*

Heterogeneity			Tau-squared			
df (*Q*)	*p*-value	I-squared	Tau Squared	Standard Error	Variance	Tau
6	.000	93.486	18	30.943	957.487	5303

According to the random effects model in Table 8, the summary effect has a z value of 3.10 and a p-value of .00 ($p < .05$). Thus, the null hypothesis claiming that there was no real mean difference between the experimental and control groups was rejected, and it was concluded that the attitudes of the students who received STEM training were statistically significantly different from those of the students who did not receive STEM training.

Table 8. *Average effect size.*

Model	Number of Studies	Effect size and 95% confidence interval					Test of null (2-Tail)	
		Point Estimate	Standard Error	Variance	Lower Limit	Upper Limit	*z*-value	*p*-value
Fixed	7	0.723	0.158	0.025	4.413	1.033	4.567	.000
Random	7	7.279	2.349	5.519	2.674	11.883	3.098	.002

3.4. Publication Bias Tests

Figure 5 shows the funnel plot test results of the individual studies included in the meta-analysis. When Figure 2 is analysed, it is observed that individual studies are not symmetrical in a way that may lead to publication bias and are located at the bottom of the graph. In order to make a general inference for publication bias, other publication bias tests need to be performed (see, Table 9).

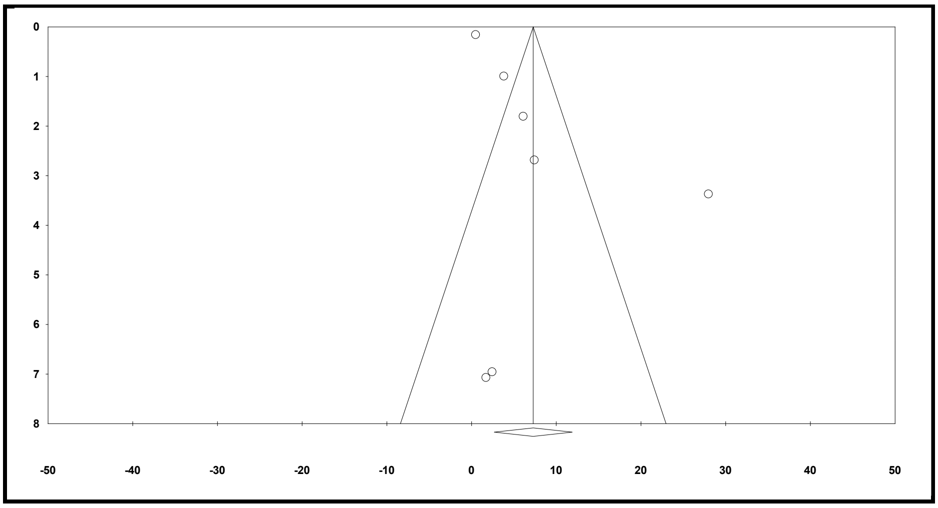

Figure 5. *Funnel scatter plot.*

Table 9. *Publication bias tests.*

Classic Fail-Safe *N*	Egger regression (*p*-value 2-tailed)	Kendall *Tau b*	Duval Tweedie's trim and fill (random effect)	
			Studies trimmed (to the right)	SMD observed (adjusted)
120	.06	-0.09	0	0.72-0.72

Based on the results of the Classic fail-safe N test, it can be inferred that an additional 120 studies would be required in the analysis to indicate the presence of publication bias in this meta-analysis ($.05 < p$). Since it is not possible to reach this number of studies in this research area, this result shows that there is no publication bias. According to the Egger regression test results, the *p*-value was found to be above .05 (.06), and according to this result, our meta-analysis study does not carry publication bias.

The Begg and Mazumdar rank correlation test shows that the Kendall tau *b* coefficient takes a negative value quite far from 1. However, since the *p*-value was not statistically significant (*Tau b* = -0.09; *p*-value (two-tailed) .72, $p > .05$), it can be interpreted that there is no publication bias in the study. When the results obtained from Duval Tweedie's trim and fill method are analyzed, the adjusted *SMD* results of the truncated studies reveal that there is no difference in the dimensions and directions of the variables that may lead to publication bias.

When the evidence obtained from the publication bias tests is evaluated in general, it can be stated that all tests except the funnel plot test show that the meta-analysis study does not have an analysis unit that may lead to publication bias; in other words, the study unit included in the analysis does not carry publication bias.

4. DISCUSSION and CONCLUSION

The meta-analysis method has emerged as a comprehensive literature review involving the use of a systematic approach and statistical formulae. It is an undeniable fact that each of the scientific studies, which are the products of the research carried out by individual researchers to contribute to science with intensive labour, is very valuable (Aksoy Kürü, 2021). This meta-analysis study aims to examine the effect of STEM education on students' attitudes and achievement levels. Based on the calculations, it has been concluded that in the 22 studies included in the meta-analysis (15 related to academic achievement; 7 related to student attitudes), the effect of STEM education on students' attitudes and achievement towards the course is more positive compared to other methods according to the fixed effects model. In addition, since the effect size value was greater than 0.80, it has been determined to have a high effect level compared to Cohen's classification (Cohen, 2007). According to the results obtained, STEM practices have a positive impact on students' overall achievement levels. It was revealed that there was an individual difference in the scores. Since the learning of individuals depends on the differentiation in their minds, it is considered normal that the amount of increase in scores is at different levels. Nadelson *et al*. (2015) argue that the most important determinant of success in design courses is the individual learning capacity of the student. Similar results were found in the studies on STEM applications in the literature. For example, Abdelrahem and Asan (2006) stated that the design processes that students continue with their own experiences increase academic achievement, and Barker *et al*. (2010) stated that students' content knowledge changed positively in favour of the post-test in STEM applications. Wendell and Rogers (2013) stated that according to the results of STEM research, a significant increase was observed in the achievement level of students compared to the control group. In their study, Yıldırım and Altun (2015) also stated that academic achievement increased in courses conducted with a STEM approach. In addition to these results, Navruz *et al*. (2014) stated in their study that success in the teaching processes that students encounter newly cannot always be at a high level and positive. This finding suggests that STEM education has a highly positive impact on students' attitudes towards the related course and academic achievement compared to other methods. This finding suggests that STEM education enhances students' attitudes towards the course and academic achievement. In STEM education practices, students learn theoretical information in a more engaging and interactive manner, rather than in a monotonous way, through the STEM education model. STEM increases the creativity of the individual by developing innovative thinking. When mathematics, engineering and technology fields are combined by placing the science course in the focus, a permanent knowledge pool is formed in the lives of students. Similarly, Yamak *et al*. (2014) reported that STEM education improved students' scientific process skills, such as identifying and defining problems, researching, questioning, and solving problems, and that the designs created by students in the classroom helped them develop a positive attitude towards science classes. Additionally, Strong (2013) observed that the engineering design process applied to elementary school students improved their scientific process skills.

According to Cohen (2007), the effect size classifications indicate that the impact of STEM education on students' attitudes towards the course and academic achievement levels has been determined to have a high and positively oriented effect size. This finding indicates that STEM education has a positive effect on students' attitudes towards the course and academic success level. Upon reviewing the literature, it is evident that STEM education has a positive impact on students' attitudes towards the course and academic achievement (Abanoz, 2020; Atik, 2019; Aydın, 2019; Bal, 2018; Borenstein *et al*., 2009; Breiner *et al*., 2012; Kalyoncu, 2021; Tatli, 2022). On the other hand, the meta-analysis study conducted by Değerli (2021) concluded that STEM education has a positive and broad impact on developing students' scientific process skills. This finding aligns with the research results. The study conducted by Lestari et al. (2018) indicated that STEM activities have a positive impact on students' scientific process skills. The meta-analysis conducted by Kim *et al*. (2018) also revealed that STEM education contributes to students' higher-level skills. In fact, research conducted by Bircan and Çalışıcı (2022) determined that STEM applications not only positively affect scientific process skills but also have an impact on 21st-century skills, including critical thinking, collaboration, communication, creativity, and sharing. In the meta-synthesis study on STEM education conducted by Herdem and Ünal (2018), positive effects on students' scientific process skills, academic achievement, attitudes, career awareness, and engineering processes were highlighted. The current scenario further corroborates the findings of the research. According to the findings obtained from the meta-analysis research conducted by Kazu and Kaplan (2024), it was determined that the effect of STEM applications on science process skills was positive and at a moderate level (g = 0.992). This circumstance currently reinforces STEM education's positive and beneficial impact on students' attitudes towards the course and academic achievement levels. Similarly, Yamak *et al*. (2014) concluded that STEM education leads to improvements in students' scientific process skills and helps them develop positive attitudes towards science. Saçan (2018) found that the STEM-based curriculum improves the scientific process skills of seventh-grade students, increases their motivation towards STEM, and positively affects their attitudes towards socio-scientific issues. Toma and Greca (2018) observed that the integrative STEM learning model based on inquiry helped students to develop positive attitudes towards science and increased their academic success.

Apart from student achievement and attitude, the increasing importance of STEM in the global economy and society has brought these disciplines to the forefront of educational reform. Policymakers and educators are focusing on how best to prepare students for a future in a world shaped by technology, innovation, and complex global challenges. In this context, it is essential to consider both policy and practice implications for improving STEM education. So, both policy and practice play critical roles in shaping the future of STEM education. Policymakers need to prioritize funding, curriculum reforms, teacher preparation, and inclusivity to ensure that all students are equipped with the necessary skills for success in STEM fields. At the same time, educators must implement innovative and interdisciplinary teaching strategies, integrate technology, and provide opportunities for students to develop both technical and soft skills. The synergy between policy and practice will ultimately foster a robust and inclusive STEM education system that prepares students for the challenges and opportunities of the future.

The analysis reveals that STEM practices have not only a generally positive effect on students' academic achievement, motivation, problem-solving skills, and engagement but also provide critical evidence to inform educational practice and policy development. These insights are essential for ensuring that STEM education reforms are not only innovative but also grounded in empirical data that reflect local needs and realities. Based on these findings, several instructional recommendations are presented, particularly regarding curriculum development, teacher training, classroom practices, assessment methods, and policy implications. Findings from the meta-analysis suggest that integrated STEM education significantly enhances students' academic outcomes (Çetin & Türkan, 2020). Therefore, curriculum designers should promote cross-disciplinary approaches that merge scientific inquiry with technological and mathematical applications. Interdisciplinary units and thematic instruction can create more coherent and engaging learning experiences (Kelley & Knowles, 2016). On the other side, the positive effects of STEM programs are especially prominent when learning is experiential and student-centered. Therefore, project-based, inquiry-based, and problem-based learning approaches should be prioritized. These strategies align with constructivist principles and foster deeper understanding through hands-on exploration (Capraro & Slough, 2013). The meta-analytic findings offer a robust foundation for improving both practice and policy in STEM education in Turkey. When translated into actionable strategies, these results can support a more effective, equitable, and future-ready education system aligned with national development goals.

As a result, the effects of STEM applications on students' academic achievement and attitudes were examined, and different effects other than these were excluded from the scope of the study. Researchers planning to conduct a study are advised to examine current studies that apply STEM education to various courses and materials, utilizing technology to support STEM education. Within the scope of STEM education, meta-analysis studies can be carried out on different subjects, such as their effects on various factors, including motivation and retention. The possible causes of regional differences in statistics attitudes-achievement relationships should be explored. Meta-analyses that include all statistics attitudes-achievement research, regardless of the attitude survey used, should be conducted. Finally, recognizing the limitations of the study is crucial for interpreting the findings with appropriate caution. Nevertheless, the current meta-analysis provides a meaningful synthesis of the available evidence on STEM education in Turkey and offers practical insights for educators and policymakers. So, future research should aim for more standardized reporting, include longitudinal data, and explore the role of contextual factors in greater depth.

Declaration of Conflicting Interests and Ethics

The authors declare no conflict of interest. This research study complies with research publishing ethics. The scientific and legal responsibility for manuscripts published in IJATE belongs to the authors.

Contribution of Authors

Abdulkadir Kurt: Resources, Methodology Research design, Visualization, Data collection, Data Analysis Writing-original draft. **Muhammed Akıncı**: Resources, Methodology Research design, Data collection, Supervision, Critical Review.

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APPENDIX

Appendix A. Descriptive properties of the studies included in the meta-analysis

No	Title	Author(s)	*N*	Sample Characteristics
1	The effects of science technology-Engineering math (STEM) integration on 5th-grade students' perceptions and attitudes towards these areas	Gülhan and Şahin (2016)	57	5th-grade students
2	An examination of the effects of stem applications prepared in accordance with context-based learning	Yıldırım (2018)	26	Pre-service teachers
3	The Effects of STEM Activities on STEM Attitudes, Scientific Creativity and Motivation Beliefs of the Students and Their Views on STEM Education	Ugras (2018)	50	7th-grade students
4	Effect of STEM Activities on Students' Scientific Process Skills, Science Interest, Attitude, and Student Opinions	Simsek (2019)	52	7th-grade students
5	Investigation of the Effects of STEM Activities on Pre-Service Teachers' Self-Efficacy Beliefs and their STEM Intention Levels	Timur and Belek (2020)	104	Pre-service teachers
6	The Effect of Stem Applications on Students' Perceptions and Attitudes Towards Stem in The 6th Grade Science Course	Bahadır and Kose (2021)	73	6th-grade students
7	The Effects of Montessori Approach-Based STEM Activities on Pre-service Teachers' Attitudes Towards Science and Science Teaching	Cakir and Yalcin (2021)	100	Pre-service teachers
8	An Investigation of the Effects of STEM based Activities on Pre-service science Teachers' Science Process Skills	Gokbayrak and Karisan (2017)	50	Pre-service teachers
9	An Experimental Research on Effects of STEM Applications and Mastery Learning	Yildirim and Selvi (2017)	52	7th-grade students
10	The Effect of STEM Applications on 7th-Grade Students' Academic Achievement, Reflective Thinking Skills, and Motivations	Cakir and Ozan (2018)	53	7th-grade students
11	Teaching Applications' Based On 7E Learning Model Centered STEM Activity Effect on Academic Achievement	Guven, Selvi and Benzer (2018)	37	5th-grade students
12	The Effects of STEM Training on the Academic Achievement of 4th Graders in Science and Mathematics and their Views on STEM Training Teachers	Acar, Tertemiz and Tasdemir (2018)	47	4th-grade students
13	The Impact of Teaching the Subject "Pressure" with STEM Approach on the Academic Achievements of the Secondary School 7th-Grade Students and Their Attitudes Towards STEM	Özcan and Koca (2019)	33	7th-grade students
14	The Effect of Stem Activities on Pre-school Students' Scientific Process Skills	Keçeci, Aydın and Zengin (2019)	24	Pre-school students
15	The Effect of STEM Activities on Students' Achievement in "Sound" Subject	Dedetürk, Kırmızıgül and Kaya (2019)	158	6th-grade students
16	An Investigation the Effect of STEM Practices on Fifth Grade Students' Academic Achievement and Motivations at The Unit "Exploring and Knowing the World of Living Creatures"	Parlakay and Koç (2020)	64	5th-grade students
17	The Effect of STEM Implementation on Attitude Towards Stem And Success in "Measurement of Force and Friction" Class	Ozan and Sagir (2020)	20	5th-grade students
18	The Effects of STEM Activities on 8th-Grade Students' Science Process Skills, Scientific Epistemological Beliefs, and Science Achievements	Bahsi and Fırat (2020)	32	8th-grade students
19	The Effect of Stem Applications on the Stem Awareness of Students and the Performance of the Success in the "Triangles" Unit	Gürbüz and Karadeniz (2020)	33	9th-grade students
20	The Effect of The Stem Approach Based on the 5E Model on Academic Achievement and Scientific Process Skills: The Transformation of Electrical Energy	İzgi and Kalaycı (2020)	50	7th-grade students
21	The Effect of STEM Activities Prepared According to the Design Thinking Model on Pre-school Children's Creativity and Problem-Solving Skills	Yalçın and Erden (2021)	39	Pre-school students
22	The Effect of STEM-based Education Program on Problem-Solving Skills of Five-Year-old Children	Şahin (2021)	37	Pre-school students