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A Meta-Analysis of the Effects of Different Integrated STEM (Science, Technology, Engineering, and Mathematics) Approaches on Primary Students' Attitudes

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The purpose of this meta-analysis is to combine the results of experimental research completed between 2012 and 2022 and to examine the effects of different integrated STEM approaches on the attitudes of elementary school children. In the meta-analysis for the study on the effects of several integrated STEM approaches on the attitudes of elementary school children, five studies were selected based on particular criteria. The study included subgroup analyses in addition to exposing the overall effect of various integrated STEM approaches on the attitudes of elementary school children. According to the research findings, the Hedges g value, which is calculated to be 0.279 for the total effect size of diverse integrated STEM approaches on the attitudes of elementary school pupils, shows a small influence. In addition, the results of the analysis revealed that the impacts of different integrated STEM approaches on the attitudes of primary school pupils did not differ according to grade levels, but differed according to attitude area and integration. The results of the present study support the need for additional research on STEM-integrated learning activities that influence student motivation and pursuit of STEM jobs.

Keywords: STEM, integration, meta-analysis, primary school

INTRODUCTION

Several publications have criticized the current education system for failing to provide pupils with 21st-century science and technology education and for failing to satisfy labor market demands (European Commision, 2016; UNESCO, 2015). These published findings have intensified attempts to improve education systems. In this context, STEM (Science, Technology, Engineering, and Mathematics) education is a strategy to education reform that integrates the teaching of science, technology, engineering, and mathematics from pre-school through higher education (Akgündüz vd., 2015). In the report of STEM 2026, it was emphasized that interdisciplinary approaches to teaching and learning across STEM disciplines and non-STEM disciplines may be more effective than simple traditional approaches because they allow children to explore STEM concepts in more interactive and engaging ways. Currently, it does not appear possible for students to gain abilities such as creativity, critical thinking, problem solving, and collaborative working through the classical education model based on the industrial age style. The current educational system teaches science, maths, and technology topics separately to students. This could be considered "Traditional STEM" (Akgündüz vd., 2015). In order to distinguish the current trend of STEM education from the conventional STEM education, global government policies have stressed integration in STEM education (Cheng & So, 2020; Wan, So, & Zhan, 2022).

Some authors have coined the term "Integrative STEM Education" due to the evolution of the term STEM education. "Integrative STEM Education" is their term for STEM education that integrates diverse fields in an interdisciplinary manner (Sanders & Wells, 2006). "Integrative STEM Education" which is defined as a technology or engineering design-based teaching approach that consciously integrates the concepts and applications of scientific and/or mathematical education with the practical concepts of technology and engineering education, can also be integrated with other tools (art, social sciences, language, etc.) (Martín-Páez, Aguilera, Perales-Palacios, & Vílchez-González, 2019).

The learning outcomes of integrative STEM are frequently studied areas (Bedar & Al-Shboul, 2020; Duran, Höft, Lawson, Medjahed, & Orady, 2014; Friedman, Melendez, Bush, Lai, & McLaughlin, 2017; Gallant, Bork, Carpenter-Cleland, & Good, 2020; Han, 2017; Julià & Antolí, 2019; Lamptey vd., 2021; Master, Cheryan, Moscatelli, & Meltzoff, 2017; Mohr-Schroeder vd., 2014; Zhou, Zeng, Xu, Chen, & Xiao, 2019). In addition, the effectiveness of integrated STEM education in generating basic topic knowledge has been relatively understudied, according to some scholars (Barrett, Moran, & Woods, 2014; Honey, Pearson, & Schweingruber, 2014).

However, successful integration in authentic STEM classrooms is intricate and challenging (Ryu, Mentzer, & Knobloch, 2019). In elementary schools, this scenario may be considerably less convoluted and straightforward. The lower the grade level, the easier it may be to incorporate STEM learning activities with

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an interdisciplinary focus into the curriculum (Irish Department of Education, 2020). In addition, elementary school teachers are general educators. Primary school instructors are more acclimated to interdisciplinary curriculum implementation than secondary school teachers (Duran vd., 2014; Lesseig, Nelson, Slavit, & Seidel, 2016; Ring, Dare, Crotty, & Roehrig, 2017). In addition, widespread emphasis has been placed on the necessity for early deployment of integrated STEM education and instruction (Bybee & Fuchs, 2006; Dubosarsky Mia, and John, Florencia, Susmitha, & Ugur, 2018). Young learners are inherently curious, imaginative, and collaborative, all of which are required for integrative learning (Banko, Grant, Jabot, McCormack, & O'Brien, 2013). In addition, students' fundamental STEM skills and attitudes are developed during primary education, which is vital for their future development (Nadelson vd., 2013). Moreover, it is particularly important to promote favorable attitudes among primary school children toward integrated STEM approaches, given that early experiences can play a key influence in fostering good views (Wells & Lekies, 2006). Future attempts to establish a holistic curriculum and prepare education programs for STEM education in primary schools should not be jeopardized by the complexity of STEM integration, despite all of the variables that facilitate its implementation. Meta-analyses are seen as crucial because educators, policymakers, and decision-makers rely on their findings. Researchers rely on meta-analyses to inform their existing understandings of important research problems and to uncover knowledge gaps. In addition, relevant meta-analyses are a key step in providing sufficient evidence to support STEM integration arguments (Pigott & Polanin, 2020).

Different integrations of studies relating to integrated STEM approaches in elementary schools garner interest (Boeve-de Pauw vd., 2020; Chiang, Chang, Wang, Cai, & Li, 2022; Fernández-Cézar, Garrido, & Solano-Pinto, 2020; Li, Huang, Jiang, & Chang, 2016; Thomas, 2013). For the future of Integrated STEM learning approaches in primary schools, it is essential to consolidate all experimental research results connected to scientific research outcomes, given that diverse integrated STEM learning techniques contribute to the attitudes of primary school children. In order to determine the most successful integration for fostering positive attitudes about integrated STEM approaches among students, it is essential to examine the outcomes of several types of applied integrations.

In this backdrop, the purpose of this study is to conduct a meta-analysis of the effects of various integrated STEM approaches on the attitudes of primary school children between 2012 and 2022. In this context, we seek answers to the following research questions:

1. What influence do various integrated STEM initiatives have on student attitudes?

2. Does the magnitude of the joint effect of integrated STEM approaches on student attitudes vary by class, attitude area, and type of integration?

METHOD

In the relevant literature, there are sufficient research assessing the effects of diverse integrated STEM approaches on student views. By compiling the results, it is possible to draw a broad conclusion about the effect of different integrated STEM approaches on student views. This study used meta-analysis, which combines the findings of multiple studies into a single conclusion (Şen & Yıldırım, 2020). In other words, it is a quantitative overview of the study's findings (Pigott & Polanin, 2020).

This study examines the effects of multiple integrated STEM approaches on student attitudes through experimental research. The approach of meta-analysis was utilized to determine the total effect size and gain a holistic picture. In this sense, the inquiry investigated experimental studies examining the effects of diverse integrated STEM approaches on student attitudes between 2012 and 2022. Scopus and Web of Science databases were scanned for the study and while scanning, it was aimed to reach all studies written in English. The scanning process was completed in June 2022. In addition, studies that met the inclusion criteria were accordingly included.

The inclusion of research was based on the following criteria:

(1) Those published between 2012 and 2022,

(2) Scholarly works published in English,

(3) Experimental research assessing the impact of integrated STEM initiatives on student attitudes,

(4) Studies with appropriate statistical data to assess effect sizes,

(5) Studies at the elementary school level.

Using EBSCO Academic Search Ultimate, "STEM, attitude, experimental" keywords were utilized to meet these criteria. The PRISMA protocol was used in the meta-analysis.

Figure.1 Flow diagram

Following the order of the inclusion criteria, relevant keywords were filtered according to their scope. It was verified that the result is unaffected by the filtering order. The most extensive search produced 84 studies. The application of all criteria resulted in the inclusion of five papers matching the research criteria. After an exhaustive search, inappropriate studies were excluded. Due to the fact that one of the five studies included three dependent variables, seven effect sizes were determined for the analysis (Figure 1).

Examining the descriptive information of the included studies reveals that the experimental studies included in the research are for the second, fourth, and fifth grade levels. In addition, the fifth grade is the primary school level in the countries where the participants of the research included in the meta-analysis resided. The ages of the participants range from 9 to 12 years old. In these investigations, Math, Technology, and general attitudes were probed. There are a total of 2397 students participated in the analysis. In meta-analysis research, with the exception of a common effect size estimation, it is essential to collect data for subgroups to discover instances in which the impact size may differ (Kurt, Yıldırım, & Cücük, 2018). This study was motivated by the effect of several integrated STEM initiatives on student perceptions. This is why integration was considered a moderator. In addition, attitude domains and social class were deemed significant and utilized as moderators.

Table 1: Descriptive Data Relating to the Involved Studies

Study	Grade	Attitude area	Integration
Fernández-Cézar et. al. (2020)	Fifth Grade	Math attitudes	Interaction with STEM researchers
Chiang et. al. (2022)	Second Grade & Fourth Grade	General attitudes	Engineering based learning
Boeve-de Pauw et. al. (2020)	Fifth Grade	Technology attitudes	Interactive classroom
Thomes, M.E (2013)	Fourth Grade	Math attitudes	STEM curriculum
Li et. al. (2015)	Fourth Grade	Math attitudes	Engineering based learning

To ensure proper coding, all data were independently coded by two different Educational Sciences researchers, and 100% compliance with the codes was attained. In the analysis, Hedges' g was preferred because the sample size in several studies was fewer than 20. In addition, CMA 2.0 was employed for data analysis.

Examining publication bias to test the validity of predicted common effect sizes. The funnel plot, Duval and Tweedie's approach, and Rosenthal's fail-safe N methods were utilized to test for publication bias resulting from the inclusion of studies in the meta-analysis.

RESULTS

In this part, the overall effect size and subgroup analysis data will be given with the study questions.

a) The Results Concerning Effect Size

In Table 2, the effect sizes and homogeneity/heterogeneity test findings for two distinct models (fixed effects and random effects) derived by integrating the data of the studies included in the meta-analysis are displayed. In addition, effect sizes and test findings for heterogeneity are provided in Table 2.

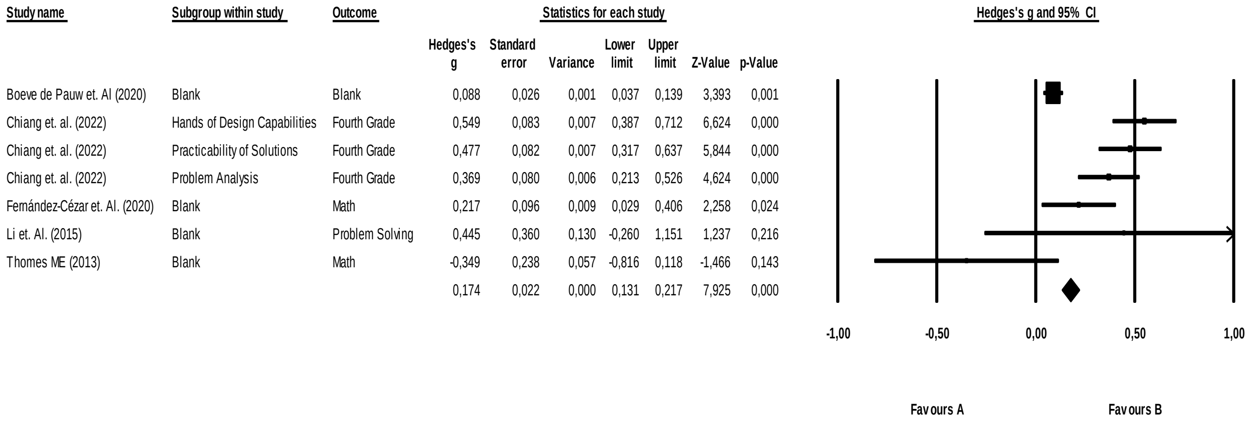
Table 2: Effect sizes and heterogeneity test results

Model	n	Common effect size	Z	Standart Error	95% Confidence interval		df	Q	p	I^2
					Lower limit	Upper limit				
Fixed effects model	7	0,174	7,925	0,022	0,131	0,217	6	56,891	0,000	89,453
Random effects model	7	0,279	2,793	0,100	0,083	0,475				

As a result of the meta-analysis, the effect size was assessed to be 0.174 with the fixed effects model, and it was estimated to be 0.27 with the social sciences' random effects model. As a result of the heterogeneity test, the calculated statistical value of Q was 56,891. According to the chi-square table, the acceptable critical value for a significance level of 95% is 12,592 with 6 degrees of freedom. The determined statistical value of Q (56,891) is more than the crucial value of 12.592. The Q value therefore indicated that the data were diverse. In addition, the I^2 value provides a more precise heterogeneity. In this investigation, the calculated I^2 value was 89.45%. This figure suggests a significant amount of diversity. In meta-analysis studies in the field of Social Sciences, it is recommended to use random effects models for effect size analysis (Pigott & Polanin, 2020).

The forest plot in Figure 2 illustrates the distribution of impact sizes according to the random effects model.

Figure.2 Forest Plot

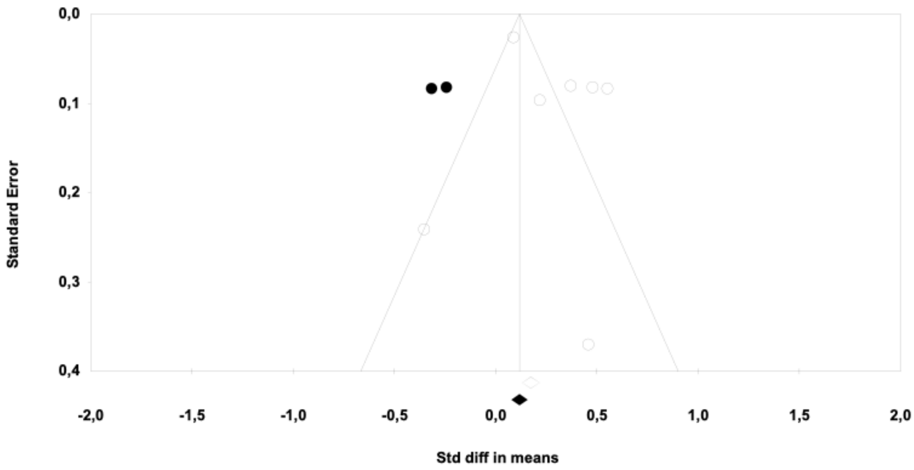


Study name	Subgroup within study	Outcome	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Boeve de Pauw et. Al (2020)	Blank	Blank	0,088	0,026	0,001	0,037	0,139	3,393	0,001
Chiang et. al. (2022)	Hands of Design Capabilities	Fourth Grade	0,549	0,083	0,007	0,387	0,712	6,624	0,000
Chiang et. al. (2022)	Practicability of Solutions	Fourth Grade	0,477	0,082	0,007	0,317	0,637	5,844	0,000
Chiang et. al. (2022)	Problem Analysis	Fourth Grade	0,369	0,080	0,006	0,213	0,526	4,624	0,000
Fernández-Cézar et. Al. (2020)	Blank	Math	0,217	0,096	0,009	0,029	0,406	2,258	0,024
Li et. Al. (2015)	Blank	Problem Solving	0,445	0,360	0,130	-0,260	1,151	1,237	0,216
Thomes ME (2013)	Blank	Math	-0,349	0,238	0,057	-0,816	0,118	-1,466	0,143
			0,174	0,022	0,000	0,131	0,217	7,925	0,000

The next crucial step in a meta-analysis is defining the effect size distribution across the included studies. The forest plot is a helpful graph that displays the effect sizes of each research together with their respective 95% confidence intervals. This graph illustrates the overall pattern of results, including the overall mean and variation around the mean (Pigott & Polanin, 2020). In the forest graphs, the black squares represent the effect sizes of the studies, while the horizontal lines through the squares represent their confidence intervals. The bigger the confidence interval, the longer the horizontal line (Gozuyesil & Dikici, 2014; Ried, 2006). Except for the study by (Boeve-de Pauw vd., 2020), it is found that the confidence intervals for the remaining investigations are relatively large. Moreover, based on the forest plot depicted in Figure 2, the research of (Chiang vd., 2022) had the biggest effect on the joint effect size, whereas the study of (Boeve-de Pauw vd., 2020) had the least effect.

b) Publication Bias

Examining publication bias served to confirm the study's reliability. The funnel plot can thus be addressed. The chart's empty circles represent the included studies, whereas the filled circles represent the fake studies that must be added to eliminate all bias (Duval & Tweedie, 2000). The "fail safe N" number is a more objective technique than funnel plots (Rothstein, Sutton, & Borenstein, 2005). In accordance with the bias statistic, the "fail safe N" value for the effect size was calculated to be 125 at a confidence interval of 0.05 Since the value of 125 is bigger than the value of 35 obtained using the 5 k + 10 calculation, it may be concluded that the findings are free of publication bias (Fragkos, Tsagris, & Frangos, 2014).



c) Subgroup Analysis

An attempt was made to estimate the source of heterogeneity by subgroup analysis. According to the characteristics of STEM integration, attitude areas, and grade level, subgroup analyses were conducted. These items are shown in Table 3.

Table 3: Analysis of subgroups using a random effects model

Variable	n	Effect size	Z	Standart Error	95% Confidence interval		df	X^2	Q_β	p
					Lower limit	Upper limit				
Level of class										
Second grade	2	0,097	3,864	0,025	0,048	0,146	6	46,928	0,975	0,614
Fourth grade	2	-0,107	-0,539	0,199	-0,497	0,282				
Fifth grade	3	0,183	4,253	0,043	0,099	0,267				
Total	7	0,116	5,387	0,021	0,074	0,158				
Attitude area										
General attitude	3	0,463	9,845	0,047	0,371	0,555	2	89,453	41,337	0,000
Math attitude	3	0,156	1,798	0,087	-0,014	0,325				
Technology attitude	1	0,088	3,393	0,026	0,037	0,139				
Total	7	0,174	7,925	0,022	0,131	0,217				
Integration										
Engineering based learning	4	0,187	4,370	0,043	0,103	0,270	3	46,928	8,837	0,032
Interactive classroom	1	0,088	3,393	0,026	0,037	0,139				
Interaction with STEM researchers	1	0,217	2,793	0,096	0,029	0,406				
STEM curriculum	1	-0,349	-1,466	0,238	-0,816	0,118				
Total	7	0,116	5,387	0,021	0,074	0,158				

Examining Table 3, the heterogeneity value of the subgroups of grade levels (QB = 0.975, p >.05) is less than the Chi-square critical values, indicating that no statistically significant difference exists between the groups. In other words, integrated STEM initiatives have little impact on the attitudes of pupils across grade levels. The fact that the subgroups of attitude areas (QB = 41,337, p .05) and integration types (QB = 8,837, p .05) exceeded the Chi-square critical values suggests that there is a statistically significant difference between the groups. In other words, the impact of integrated STEM initiatives varies depending on the attitudes of the students. The effect on attitudes in general is larger than the others. Depending on the form of integration, the effect size on student attitudes varies. Integrations that emphasize engagement with STEM researchers are more efficient than those that do not.

DISCUSSION

We indicated in the introduction that the vision of STEM education integration is tremendously significant and relevant; but, successful integration in true STEM classrooms is complex and challenging.

Numerous theoretical and practical concerns have not been investigated. Considering the intricacy of STEM integration, the significance of this meta-analysis study examining the effects of different types of integrated STEM approaches on student views is evident. Various sorts of integrated STEM techniques were analyzed in light of the experimental study outcomes. Five papers were included in the meta-analysis to investigate the effect of various types of integrated STEM initiatives on student attitudes. After reviewing the papers for publication bias, it was established that publication bias did not exist. In addition, there was a substantial degree of variation between trials. These findings are restricted to research conducted between 2012 and 2022 that experimentally explored the effects of different types of integrated STEM methods on student attitudes in elementary schools.

The study estimated that different forms of integrated STEM approaches have an effect size of 0.279 on student attitude. According to the *Hedges g* statistic, this number signifies a minor effect. This result is consistent with other meta-analysis studies in the pertinent literature, but on a different level (Kazu & Yalçın, 2021; Mustafa, Ismail, Tasir, & Mohamad Said, 2016; Saraç, 2018; Siregar, Rosli, Maat, & Capraro, 2019; Tamur vd., 2021). These studies demonstrate a moderate size of effect. The discrepancy may be attributable to the educational level and type of integration. In addition, inconsistent studies are conducted at a level above elementary school. An examination of each study reveals that a number of studies declare positive impacts of STEM techniques on student views (Aranda, Guzey, & Moore, 2020; French & Burrows, 2018; Lie, Selcen Guzey, & Moore, 2019; Nathan, Wolfgram, Srisurichan, Walkington, & Alibali, 2017; Vance, Kulturel-Konak, & Konak, 2015; Wieselmann, Dare, Roehrig, & Ring-Whalen, 2021).

In addition to analyzing the overall effect size on student attitudes, subgroup comparisons were conducted according to attitude domains, grade level, and various STEM integrations to find the cause of heterogeneity among students. As a result of the analysis, it was determined that the grade level (second grade, fourth grade, and fifth grade) did not significantly affect the influence of different types of integrated STEM methods on students' attitudes. However, attitudinal domains (general attitude, mathematics attitude, and technology attitude) and integration types (Engineering-based learning, Interactive classroom, Interaction with STEM researchers, and STEM curriculum) have significantly altered the effect of STEM approaches on student attitudes. While these results indicate that diverse STEM integrations are helpful across all grade levels, they also suggest that the influence on student attitudes will vary depending on the attitude domains and integration types. It is probable that an integration based on engagement with STEM researchers will have a significant impact, which may be explained by the elementary school level of the kids. Because elementary pupils are more receptive to learning through seeing and experiencing throughout the operational period.

SUGGESTIONS

Government and educational institutions in the United States promote the development of STEM curricula that are effectively integrated. These initiatives have also prompted the need for additional study on the benefits of integrated STEM education on the STEM learning of pupils. Similarly, additional research is required on integrated STEM learning activities that affect students' interest in and pursuit of STEM jobs (Honey vd., 2014; Kelley & Knowles, 2016; President's Council of Advisors on Science and Technology (PCAST), 2010). Did not attain the number of expected primary studies at the outset of this investigation. This substantiates the need for additional study on integrated STEM learning activities. However, the resulting sample size was sufficient to assess the magnitude of the effect. The findings suggested that the impact of various types of integrated STEM initiatives on student attitudes in elementary schools was minimal. Moreover, this meta-analysis can serve as a guidance for future research in the same area. The results of the present study support the need for additional research on STEM-integrated learning activities that influence student motivation and pursuit of STEM jobs. Eventually, this study can be repeated after some time has passed.

LIMITATIONS

The limits of this meta-analysis are the inclusion criteria.

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