

# A Meta-Analysis of the Effectiveness of Digital Technology-Assisted STEM Education

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**ABSTRACT** The purpose of this study was to reveal the effect of digital technology-assisted STEM (Science, technology, engineering, and mathematics) education on academic achievement. To achieve this purpose, experimental studies, including pre-test and post-test, were examined by meta-analysis. The study's data were obtained from 34 studies that met the inclusion criteria due to the searches made in the Databases of the National Thesis Center of the Council of Higher Education, where Turkey's postgraduate theses are located. Effect sizes of 38 comparisons were calculated from these studies. The study calculated effect sizes based on Cohen's *d* coefficient. The effect size obtained after the analysis was found to be  $d=2.582$ . This finding shows that STEM education assisted by digital technology greatly affects academic achievement. In addition, a significant difference was found between the effect sizes in the study according to the level of education and the subject discipline of academic achievement. This research is expected to contribute to educational practice and future research.

**Keywords** Digital Technology, STEM Education, Academic Achievement, Meta-Analysis

## 1. INTRODUCTION

The development of individuals also provides the development of countries. Therefore, governments strive to raise qualified individuals for their products. To increase talented individuals, countries focus on primary and essential lessons in education and, at the same time, follow up-to-date educational approaches. In recent years, the STEM education approach, which is based on the integration of various disciplines, has received significant attention (Lo, 2021; Nugroho, Permanasari, Firman & Riandi, 2021; Nugroho, Permanasari & Firman, 2019; Zhong, Liu, Xia & Sun, 2022).

The STEM education approach integrates science, technology, engineering, and mathematics. It even got its name from the initials of these fields. Although its history dates back to earlier (White, 2014; Widya, Rifandi & Rahmi, 2019), STEM was first used as "SMET" (science, mathematics, engineering, and technology) in the 1990s (Sanders, 2009). It was first used as "STEM" by biologist Judith A. Ramaley at the National Science Foundation in 2001 (Kurniawan & Susanti, 2021; National Science Foundation, 2001). In this approach, engineering and technology applications are included in the basic knowledge and skills in mathematics and science. Students learn skills related to these four areas in the designed

teaching process (Benek & Akçay, 2021). The literature emphasizes that STEM education has the advantages of interdisciplinary processing of subjects, acquiring 21st-century skills, providing mathematical modeling and computational thinking, providing a design-oriented review, and using and producing technology (Akgündüz, 2019).

While there is a significant increase in the research on STEM education, there is also a difference in the tools used to realize this education. In some studies, it is noteworthy that digital tools are used in STEM education. In STEM Practices, digital tools are used in material design or obtaining information about the subject. For example, in the research conducted by Bircan (2019), students designed a game with the Scratch program using computers in STEM education activities. On the other hand, in the research conducted by Çimentepe (2019), students watched videos on the interactive board within the scope of STEM education activities. Additionally, simulations obtained online were utilized in STEM education in the research done by Yılmaz (2019).

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Although digital tools are integrated into STEM education in various ways, there are several inconsistencies regarding their effectiveness in using them in STEM education. For example, Digital tool-assisted STEM education makes a huge difference in students' learning outcomes in some studies (e.g., Aysu, 2019, İzgi, 2020, Kağnıcı, 2019), but has a negligible effect in some studies (e.g., Bahşi, 2019, Bircan, 2019). Therefore, there is no clear conclusion about the use of these tools. In this context, it can be said that a certain opinion can be reached on the subject by combining and analyzing the findings of the studies with methods such as meta-analysis.

It is striking that there are synthesis studies examining the studies on STEM education in the literature. Some researchers have done a review the general trend of STEM education studies (Farwati et al., 2021; Nuraeni, Malagola, Pratomo & Putri, 2020; Nurwahyunani, 2021; Ormanci, 2020; Saputri & Herman, 2022; Sarıca, 2020; Setyaningsih, Ahmad, Adnan & Anif, 2021; Wardani & Ardhyantama, 2021; Zulaikha, Jumadi, Mardiani & Lutfia, 2021) and some researchers have examined the effect of STEM education on various learning outcomes by meta-analysis method (Amin, Ibrahim & Alkusaeri, 2022; Ananda & Salamah, 2021; Ayverdi & Aydın, 2020; Güder, Demir & Özden, 2022; Izzah, Asrizal & Festiyed, 2021; Jannah, Lufri, Asrizal & Putra, 2022; Karaşah-Çakıcı, Kol & Yaman, 2021; Kasuma, Asrizal & Usmeldi, 2022; Kazu & Kurtoglu Yalcin, 2021; Santosa et al., 2021; Saraç, 2018; Taşdemir, 2022; Triani, Asrizal & Usmeldi, 2022; Yüceliyiğit & Toker, 2021). In addition, it is seen that synthesis research on digital technology-assisted STEM education studies is also carried out in the literature. It is seen that these studies are mainly carried out by meta-analysis method. For example, Wang, Chen, Hwang, Guan & Wang (2022) examined the effect of digital game-based STEM education on students' learning achievement in their research. D'Angelo et al. (2014) conducted a systematic review and meta-analysis of computer simulations to support STEM learning. In their study, Jeong, Hmelo-Silver & Jo, (2019) examined the effects of Computer-Supported Collaborative Learning (CSCL) in STEM education. Belland, Walker, Kim & Lefler (2017) examined the impact of computer-based scaffolding in STEM education.

It is seen that meta-analysis studies are carried out abroad. However, no study reveals the effect of digital technology-assisted STEM education on students' learning outcomes in Turkey. To fill the gap in the literature, the effect of digital technology-assisted STEM education on students' academic achievement was examined based on the theses prepared in Turkey. This study is of great importance in guiding the studies on this subject and shedding light on the studies in Turkey. At the same time, it is of particular importance to address academic achievement, which is one of the ultimate goals of

education. Therefore, for the purpose determined in the research, answers were sought for three questions:

- 1) What is the overall effect of digital technology-assisted STEM education on students' academic achievement?
- 2) Does the effect of digital technology-assisted STEM education on students' academic achievement differ significantly according to the education level?
- 3) Does the effect of digital technology-assisted STEM education on students' academic achievement differ significantly according to the subject discipline of academic achievement?

## 2. METHOD

A meta-analysis method was used in this study, which aimed to reveal the effect of digital technology-assisted STEM education on academic achievement. Meta-analysis studies are studies that allow reaching a general conclusion from the results of different research conducted for the same problem (Büyüköztürk, Kılıç-Çakmak, Akgün, Karadeniz, & Demirel, 2016). In other words, these studies' effectiveness is examined by considering the similarities or differences of the studies conducted in the meta-analysis (Eser, Yurtçu & Aksu, 2020). This meta-analysis study tried to reach a general conclusion about the effectiveness of experimental studies based on pre-test and post-test applications. The steps taken in the research are as follows: 1) Determining the subject and research questions 2) Scanning the literature 3) Identifying the studies that meet the inclusion criteria 4) Coding 5) Performing the analyses 6) Examining the publication bias 7) Performing the heterogeneity test 8) Effect size calculations 9) Reporting (Dinçer, 2014; Şen & Yıldırım, 2020).

### 2.1. Data Collection

The research data were obtained in November 2022 from the "Databases of National Thesis Center of the Council of Higher Education", where Turkey's graduate theses are collected. To collect the data, firstly, "STEM", "education", "learning", "approach", "practice", "activity", "achievement", "science", "technology", "engineering", "mathematics", "effect" keywords were searched. The screening resulted in a list of 74 studies, and those that satisfied the inclusion criteria were chosen to be examined. The inclusion criteria of the study are as follows:

- The study examined the effect of STEM education assisted by digital technology on students' academic achievement.
- Clearly stating that digital technology (computer, interactive board, internet, smartphone, video, digital game, digital education platform, etc.) is used in its application
- The fact that the study is an experimental study with pre-test and post-test
- Availability of full text
- Include statistical information required for meta-analysis

- Conducting with typically developing students

After the examinations, it was seen that there was 34 research that met the inclusion criteria listed above. Thirty-eight effect sizes (comparison) from these identified studies were examined.

## 2.2. Data Analysis

Şen & Yıldırım (2020) state that a data table for the studies should be created after the appropriate studies are determined and quality reviews are done. Therefore, a data table was constructed in the digital environment before moving on to the data analysis. This data table includes the year, author information, study name, education level, the subject discipline of the achievement test, and statistical information about the groups. The coding process was carried out with the help of the categories in the data table. For reliability, the researcher conducted the coding process twice on different days. As a result, the coefficient of agreement between the codings was 1.0. In other words, it was observed that there was 100% agreement in the coding.

After the coding process, the data were analyzed. Analyzes can be made using formulas and meta-analysis software (Dinçer, 2014). This study used Comprehensive Meta-Analysis Software (CMA) for data analysis. The standardized mean difference was used to calculate the effect sizes. In this context, the change in academic achievement was revealed using the experimental study group's post-test and pre-test statistics. In the study, analyses were done for the overall effect size and the moderator variables. Effect sizes were calculated based on Cohen's *d* coefficient. In the interpretation of the effect sizes found, the criteria Sawilowsky (2009) suggested were based on 0.01=very small, 0.2=small, 0.5=medium, 0.8=large, 1.2=very large, and 2.0 =huge.

## 2.3. Publication Bias Reviews

Publication bias in the study was examined using the funnel plot and Rosenthal Safe N Method. The results of the Funnet plot test performed are given in Figure 1.

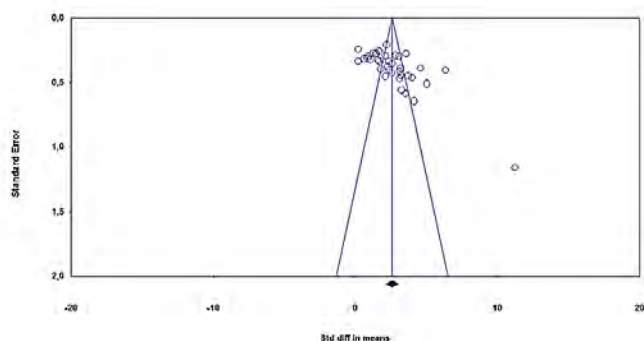


Figure 1 Funnel plot of studies

Table 1 Rosenthal Safe N method test findings

Z-value for observed studies	P- value for observed studies	Alpha	Tails	Z for alpha	Number of observed studies	Number of Safe N
41.25856	0.000	0.05	2	1.95996	38	6801

As can be seen in Table 1, it is seen that the other studies, except for the few studies, are distributed close to the vertical line symmetrically. To be sure, the publication bias analysis continued with the Rosenthal Safe N Method. Therefore, the Rosenthal Safe N Method findings are given in Table 1.

The safe N number indicates the number of studies that should be included to make the overall effect insignificant. As seen in Table 1, the Safe N number was found to be 6801 due to the Rosenthal Safe N Method test. A high value indicates that there is no publication bias.

## 3. RESULT AND DISCUSSION

In this section, firstly, findings related to heterogeneity analysis are given. Then, results and discussions on general effect size calculations and analysis of moderator variables are included.

### 3.1 Examining Heterogeneity

A heterogeneity test should be performed to calculate the overall effect because the general result can be found by determining the model in line with the findings obtained from the heterogeneity test (Dinçer, 2014). Therefore, the findings of the analyzes related to the heterogeneity test are given in Table 2.

Table 2 Findings of the heterogeneity test

df	Q-value	I <sup>2</sup>	p
37	560.135	93.394	0.000

Multiple values were examined to test its heterogeneity. One of these criteria is the p-value found due to the heterogeneity test. The result of the heterogeneity test was found to be significant ( $p < 0.05$ ). In addition, the Q value was also examined, which was found to be 560.135. It is seen that the Q value found is higher than the critical value of 37 degrees of freedom (52.192) at the 95% significance level in the chi-square distribution table.

On the other hand, the examined I<sup>2</sup> value is also high. All findings show that the distribution of effect sizes is heterogeneous. Since it is a heterogeneous feature, the random effects model was used to calculate the study's effect sizes.

### 3.2 Calculations of Overall Effect Size

The general effect size findings calculated according to the random effects model are given in Table 3, along with the lower and upper limits according to the standard error, 95% confidence interval.

As seen in Table 3, the overall effect size value was calculated as  $d = 2.582$  due to the analysis performed on the random effects model. The value found was significant,

**Table 3** Findings on the calculation of the overall effect size

Effect size ( <i>d</i> )	Standard error	95% Confidence interval		p
		Lower limit	Upper limit	
2.582	0.218	2.156	3.009	0.000

with a standard error of 0.218, a lower limit of 2.156, and an upper limit of 3.009 ( $p < 0.05$ ). The effect size shows that academic achievement is higher in favor of the post-test. Therefore, the effect size can be classified as very high.

Findings showed that digital technology-assisted STEM education significantly affects academic achievement. In other studies (D'Angelo et al., 2014; Wang, Chen, Hwang, Guan & Wang, 2022), it has been concluded that STEM education using digital technology has positive effects on learning outcomes. Therefore, it can be thought that the student's academic achievement may have increased due to the benefits of digital tools in the learning process in many ways. Güleriyüz, Dilber & Erdoğan (2020) emphasized that STEM education includes 21st-century skills such as critical thinking, creativity, innovation, problem-solving, productivity, and responsibility besides being production-oriented. In addition, it has been pointed out by some researchers that students who are introduced to STEM arduino, coding, robotics, and similar concepts may realize that their skills, such as critical thinking, reflective thinking, and algorithmic thinking, will contribute to them in all areas (Akkaş Baysal, Ocağ & Ocağ, 2020).

### 3.3 Analysis of moderator variables

The study determined the level of education and the subject discipline of academic achievement test as moderator variables. The analysis results to determine whether there is a significant difference between the effect sizes according to education level are given in Table 4.

As seen in Table 4, the effect sizes were  $d=1.257$  for primary school,  $d=2.856$  for secondary school,  $d=3.049$  for high school, and  $d=1.916$  for university. The most significant effect size belongs to the high school level, and the least effect size belongs to the primary school level. The

**Table 4** Effect sizes by education level

Education Level	n	Effect size ( <i>d</i> )	95% Confidence interval		Q <sub>B</sub>	p
			Lower limit	Upper limit		
Primary School	6	1.257	0.580	1.934	16.404	0.001
Secondary School	24	2.856	2.307	3.405		
High School	6	3.049	1.960	4.137		
University	2	1.916	1.399	2.434		

**Table 5** Effect sizes of academic achievement by subject discipline

Field of academic achievement	n	Effect size ( <i>d</i> )	95% Confidence interval		Q <sub>B</sub>	p
			Lower limit	Upper limit		
Science	32	2.838	2.381	3.294	11.776	0.001
Mathematics	6	1.255	0.475	2.035		

analysis showed a statistically significant difference between the effect sizes ( $Q_B = 16.404$ ,  $p < 0.05$ ).

The results of the analysis show that digital technology-assisted STEM education is more effective in academic achievement at the high school level. In addition, the primary school level is where STEM education assisted by digital technology has a minor effect on academic achievement. In the study by Güder, Demir & Özden (2022), in which the effect of STEM education on the scientific process skills of students in Turkey was examined, the primary school level was found to be the lowest impact. In general, it can be said that STEM education with and without digital technology assisted in primary school has less efficiency in Turkey. On the other hand, it can be thought that the results may be affected by the effect of the procedure. Therefore, practices in each study may differ. However, the effectiveness of STEM education increases in the following stages. Findings for the calculation of effect sizes according to the subject discipline of academic achievement are given in Table 5.

As seen in Table 5, the effect sizes were  $d=2.838$  for science and  $d=1.255$  for mathematics. As can be seen, the effect size of the science achievement test is larger than that of the mathematics achievement test. The analysis showed a statistically significant difference between the effect sizes ( $Q_B = 11.776$ ,  $p < 0.05$ ).

The analysis shows that digital technology-assisted STEM education is more effective in science achievement. Similarly, other research found that digital technology-assisted STEM education is less effective in the subject discipline of mathematics (Wang, Chen, Hwang, Guan & Wang, 2022). Öçal (2022) highlighted that the field of mathematics has strengths and weaknesses in the STEM education approach. The author describes students' negative attitudes and perceptions towards mathematics as weaknesses; He listed some factors, such as the difficulties they experienced in interdisciplinary integration efforts and the habits of teachers to convey information directly. Çakıroğlu & Dedebaş (2019) emphasize that mathematical concepts can be used in activities where science concepts are fundamental, but they are often very limited in terms of

mathematical thinking processes. Due to various limitations, it can be said that the effect of digital technology-assisted STEM education on mathematics achievement is less than on science achievement.

Kanematsu & Barry (2016) emphasize that STEM education is important for everyone and vital for every country's future. In this context, it can be said that it is vital to bring this study to the literature, which will shed light on increasing the effectiveness of STEM education.

#### 4. CONCLUSION

Digital tools are frequently used in STEM education, as in all areas of education. And many studies have been carried out on this subject. However, studies on this subject have primarily focused on academic achievement, which is one of the ultimate goals of education. This meta-analysis study revealed the effect of integrating digital tools into STEM education on students' academic achievement according to general and some moderator variables. The study concluded that STEM Education assisted by digital technology has a very high effect on academic achievement. In addition, it has been supposed that digital technology-assisted STEM education is more effective on academic achievement at the high school level and least practical at the primary school level. In addition, it was concluded that STEM education assisted by digital technology was more effective in science achievement.

In the future, increasing studies on a primary school level and mathematics subject discipline for digital technology-assisted STEM education is recommended. However, this research is limited to postgraduate theses in Turkey. The effectiveness of STEM education assisted by digital technology in other nations can be investigated in the future through the meta-analysis method. In addition, only academic achievement was examined in this study. In the end, the effect of digital technology-assisted STEM education on various learning outcomes, such as students' 21st-century skills, attitudes, motivations, and problem-solving skills, can be examined by meta-analysis.

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