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Research Article

The effect of STEM education practices on academic achievement and scientific process skills: A meta-analysis study

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Today's education systems, where scientific knowledge is rapidly transformed into technology, develop new teaching methods to develop the individuals needed by societies. STEM education is an application that has been proposed in the past years and enables individuals to become literate individuals in the fields of science, technology, engineering, and mathematics. The effects of STEM education based on these four disciplines on individuals' academic achievement and scientific process skills have been examined in many studies in the literature. In this direction, it is important to make a general evaluation of these studies in the literature and to make a cumulative evaluation of STEM education studies. Therefore, this study aims to perform a meta-analysis of postgraduate theses that examine the effect on academic achievement or scientific process skills based on STEM education practices. The study was conducted in phases using the PRISMA flow model. Graduate theses were published in the National Thesis Centre in 2017 and later were analysed within the framework of the inclusion criteria. As a result of the study, it was determined that STEM practices contribute positively to academic achievement and scientific process skills. As a result of the results of the study, suggestions were made for the meta-analysis of studies investigating the relationship between STEM education practices in different contexts.

Keywords: Meta-analysis, STEM, academic achievement, science process skills, postgraduate theses

1. Introduction

The dialectical interaction between science and technology in the modern age, where science affects technology and technology continuously affects science, undoubtedly affects the studies and social goals in the field (Ayvacı, Küçük & Bebek, 2023). Societies, that know the information emerging due to the quadruple cycle between technology can be dynamic and constantly changing (Ayvacı & Bebek, 2019), focus primarily on competence and skill acquisition perspectives of individuals by accelerating research and development studies and think that individuals should be equipped with skills such as problem-solving, critical thinking, creativity, and scientific process skills (Değerli, 2021). Considering the relevant requirements and developments in various fields, it would not be wrong to say that incentive education should be provided to gain the targeted skills. Concordantly, societies are confronted with two basic questions: "How should education be in the 21st century?" and "What are the skills that individuals should acquire in the 21st century?".

Although there are various definitions in the literature about 21st-century education or the education expected to be offered by societies in the 21st century, the main emphasis is on (i) conducting education about the digitalised world, (ii) adopting a practice-oriented and student-oriented approach rather than theory, and (iii) providing education with interdisciplinary approaches-methods-techniques that bring together different disciplinary fields (Gooderham, 2015). The importance of technology in the education and training environment in the digitalised world, the value of an effective field of study with an application-oriented and student-oriented perspective, and the necessity of design to appeal to different disciplinary fields reveal how important the holistic understanding is in the 21st century (Trilling & Fadel, 2009). Therefore, it can be stated that education in the 21st century should be carried out with an understanding based on the three pillars mentioned as an answer to the question "How should education be in the 21st century?".

Another question sought to be answered in 21st-century education is "What are the skills that individuals should gain in the 21st century?". Based on the education to be provided, the areas where individuals are expected to provide change are literacy skills (information literacy, media literacy, technology literacy), learning and innovation skills (critical thinking, problem-solving, creativity, communication, and collaboration), and life and professional skills (flexibility, entrepreneurship, leadership, responsibility, social and cultural skills) that enable the application of the education-digitalisation-technology conceptualization in daily life (Rotherham & Willingham, 2010). When 21st-century education and the skill areas that should be acquired by individuals in the related education process are considered, different disciplinary fields may have an impact on the acquisition of such skills by individuals in the fields in question. However, considering the semantic and conceptual framework it has, having the quality of guiding the problems waiting to be solved in daily life, including the acquisitions belonging to the disciplinary fields of technology and engineering, and the weight of the targeted acquisition, especially mathematics and science disciplines are likely to have more impact than other fields (Chalkiadaki, 2018). Considering this impact, it would not be wrong to say that the education and training process should be carried out with approaches that bring together disciplinary fields such as mathematics, science, technology, and engineering, which can affect the development of the individual's competencies and competencies in the context of the perspective of each disciplinary field, and positively support change depending on the interdisciplinary transition (Breiner, Harkness, Johnson & Koehler, 2012).

The STEM approach, which combines mathematics, science, technology, and engineering disciplines, is among the most effective approaches to gaining 21st-century competencies and competencies (Tezel & Yaman, 2017). In 2001, Dr. The concept of STEM, which was created by Dr. Judith Ramaley in 2001 by deriving from the initials of the words Science (science), technology (technology), Engineering (engineering), and Mathematics (mathematics) (Bybee, 2013), is directly related to daily life (Değerli, 2021) and is defined as an educational approach that aims to raise individuals who can establish meaningful connections between different disciplines, question, investigate, and produce solutions (Bybee, 2010; Brown, Brown, Reardon & Merrill, 2011; Gonzalez & Kuenzi, 2012). The realization of imagined designs, the integration of existing knowledge with the designs obtained, and the development of social skills such as cooperation and respect are carried out within the scope of STEM education (Gomez & Albrecht, 2014; Sanders, 2009). Gencer (2015), who emphasizes that individuals should be trained as engineers in STEM education, states that they should start life one step ahead as individuals who are respectful and open to different ideas, who use their cooperation skills effectively, who can choose the most appropriate way while producing solutions to problems, and who can establish connections between different disciplines. Karataş (2018), on the other hand, mentions that although the need for numerical occupational fields such as engineering, science, and mathematics has increased with the development of science and technology in our country, the number of qualified students applying to these fields is low. However, STEM education is important in terms of multidimensional learning of individuals who can use high-level skills and bring together different disciplines (Riechert & Post, 2010). On the other hand, in many countries such as the USA, Finland, Brazil, the UK, South Korea, and China, it is possible to come across significant studies on STEM education and application areas both based on programmes and interaction (Tabar, 2018). In our country, studies based on the STEM approach have started to be carried out with the discussions that emerged because of the low performance in exams such as TIMMS and PISA, which are international student assessment research exams, and the initiative of the private sector (Herdem & Ünal, 2018). The importance of the relevant approach has been taken into consideration by the researchers so that various studies on the applications and importance of STEM education in the education process are found in the national and international literature. STEM education has been found to improve academic achievement (Bebek, 2021; Becker & Park, 2011; Wai, Lubinski, Benbow & Steiger, 2010; Tabaru, 2017), scientific process skills (Alan, 2020; Tabaru, 2017), critical thinking skills (Acar, 2018; Bebek, 2021; Hacıoğlu, 2017), engineering skills (Ayverdi, 2018), problem-solving skills (Bicer, Nite, Capraro, Barrosso, Capraro & Lee, 2017; Ceylan, 2014; Tabaru, 2017), 21st-century skills (Külegel, 2020) and creativity (Bicer, Nite, Capraro, Barrosso, Capraro & Lee, 2017; Gülhan, 2016; Hacıoğlu, 2017). The fact that studies have been conducted on the effect of STEM education on academic achievement and skill groups makes it reasonable to evaluate the results obtained in the relevant studies and to evaluate them from a broad perspective. Concordantly, there are studies (Büyüköztürk, Kılıç Çakmak, Akgün, Karadeniz & Demirel, 2016) that try to evaluate the research conducted on a determined subject or purpose as a whole and reach generalizations from the results obtained in these studies and to guide researchers (Bakioğlu & Özcan, 2016). Within the scope of the research, it aims to evaluate the studies carried out in the subject area to examine the effect of STEM education practices on academic achievement and scientific process skills and to present these studies by comparing them. Concordantly, the research sought to answer the following four questions.

RQ 1) What is the overall impact level of STEM applications on academic achievement?

RQ 2) Does the effect of STEM applications on academic achievement differ significantly according to publication type, education area, sample group, implementation period, and the category of publication year moderators?

RQ 3) What is the overall impact level of STEM applications on scientific process skills?

RQ 4) Does the effect of STEM applications on scientific process skills differ significantly according to publication type, education area, sample group, implementation period, and the category of publication year moderators?

2. Method

2.1. Research Model

This study was conducted to examine the effect of STEM education practices on academic achievement and scientific process skills. Graduate theses published in the National Thesis Centre in 2017 and later were included in the study and the studies were evaluated by meta-analysis method. The meta-analysis method is defined as grouping similar studies on a subject, theme, or field of study under certain criteria and combining and interpreting the quantitative findings of these studies (Dinçer, 2014). In meta-analysis studies, the studies collected in meta-analysis studies are examined for their suitability within the scope of predetermined criteria their inclusion/exclusion status is examined, and a flow diagram called PRISMA is created (Moher, Liberati, Tetzlaff, & Altman, 2009). The PRISMA flow is presented in Figure 1.

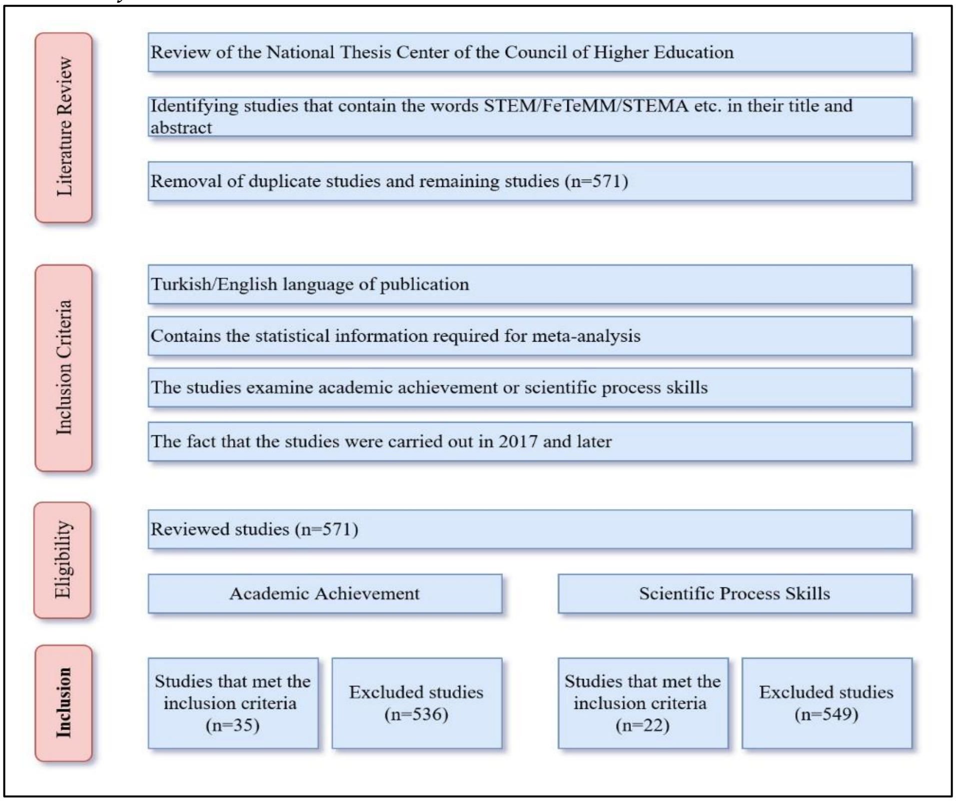
2.2. Data Collection

The National Thesis Centre of the Presidency of the Council of Higher Education was used to collect the data. In the search, studies with STEM/STEM/STEMA in the title and abstract of the study were identified. Then, those with the title of Education and Training were downloaded to be examined in detail.

2.3. Inclusion/Exclusion Criteria

This study determined the following conditions as inclusion criteria for the studies to be included in the meta-analysis. Studies that did not meet these inclusion criteria were excluded from the study. (i) The language of publication should be Turkish or English, (ii) It should provide the statistical information required for meta-analysis (sample size, arithmetic mean, standard deviation, p-value, t-value, etc.), (iii) The study should examine academic achievement or scientific process skills, and (iv) The publication year of the study should be 2017 and later, depending on the fact that the updates based on the STEM approach will be reflected in the 2018 curricula and these reflections were presented in the draft programs in 2017.

Figure 1
PRISMA flowchart



2.4. Data Coding

Microsoft Excel programme was used for the coding process of the study. The information of the studies that met the inclusion criteria was kept under the titles of Sequence No, Type, File-CMA Name, File Name, Author, Publication Year, Thesis Title, University, Publication Type, Outcome, Education Level, Education Duration, Experiment_N, Experiment_X, Experiment_ss, Control_N, Control_X, Control_ss, Explanation, Type of Analysis. To ensure coding reliability, the coding process was carried out by two authors. The agreement between the coders was calculated and the reliability for academic achievement was 94.29% and 95.45% for science process skills. Inconsistencies between the coders were discussed and corrections were made by reaching a consensus. In the studies, the effect of STEM applications on academic achievement and scientific process skills was also addressed by the moderators. Concordantly, moderators were determined as publication type, education area, sample group, implementation period, and the category of publication year (1= Theses conducted in 2017 or 2018, 2= Theses conducted in 2019 or 2020, 3= Theses conducted in 2021 or 2022). Information about the studies included in the meta-analysis process is given in Table 1 and Table 2.

2.5. Calculation of Effect Size and Statistical Methods

Today, programmes such as Meta-Win and CMA (Comprehensive Meta Analysis) are preferred to calculate effect size. Meta-Win software focuses on calculating the effect size over uniform individual studies. For example, sample size, arithmetic mean, and standard deviation values are sufficient to calculate the overall effect in the meta-analysis process. On the other hand, CMA software can combine individual studies with different data types. Therefore, CMA software can take different data types into account when calculating the effect size of individual studies and the overall effect. As a result, CMA software was preferred to evaluate studies with different data types together.

Table 1
Information on included studies (academic achievement)

Thesis No	*Thesis Type*	*Education Area*	*Sample Group*	*Implementation Period*	*Category of Publication Year*
467613	Master's Degree	Science	Secondary School	1-6 Weeks	1
490625	Master's Degree	Science	Secondary School	1-6 Weeks	1
498288	Master's Degree	Science	Secondary School	7-12 Weeks	1
506210	Master's Degree	Science	High School	7-12 Weeks	1
509021	Master's Degree	Science	Secondary School	1-6 Weeks	1
510413	Master's Degree	Science	Secondary School	1-6 Weeks	1
522774	Master's Degree	Science	Secondary School	1-6 Weeks	1
527021	Master's Degree	Science	University	1-6 Weeks	1
527233	PhD	Science	Primary School	7-12 Weeks	1
530773	Master's Degree	Science	Secondary School	1-6 Weeks	1
533367	PhD	Science	High School	1-6 Weeks	1
541728	Master's Degree	Science	University	7-12 Weeks	1
546356	Master's Degree	Science	Secondary School	1-6 Weeks	2
546488	Master's Degree	Science	Secondary School	7-12 Weeks	2
552833	Master's Degree	Science	Secondary School	1-6 Weeks	2
556449	PhD	Science	Secondary School	13-18 Week	2
562872	Master's Degree	Science	Secondary School	1-6 Weeks	2
568332	Master's Degree	Science	Secondary School	1-6 Weeks	2
572881	Master's Degree	Science	High School	1-6 Weeks	2
573011	Master's Degree	Science	Secondary School	1-6 Weeks	2
583364	Master's Degree	Science	Secondary School	7-12 Weeks	2
600005	Master's Degree	Science	Secondary School	1-6 Weeks	2
620030	Master's Degree	Science	Secondary School	7-12 Weeks	2
621137	Master's Degree	Science	Secondary School	1-6 Weeks	2
628340	Master's Degree	Science	Primary School	1-6 Weeks	2
635609	Master's Degree	Science	Secondary School	1-6 Weeks	2
641693	Master's Degree	Computer and Instruction	Secondary School	7-12 Weeks	2
643390	Master's Degree	Science	Secondary School	1-6 Weeks	2
644523	Master's Degree	Science	University	7-12 Weeks	2
660696	Master's Degree	Maths	Secondary School	1-6 Weeks	3
672056	Master's Degree	Science	Secondary School	1-6 Weeks	3
713933	Master's Degree	Science	University	13-18 Week	3
743510	Master's Degree	Science	Secondary School	7-12 Weeks	3
755826	Master's Degree	Science	Secondary School	7-12 Weeks	3
772819	Master's Degree	Science	Primary School	1-6 Weeks	3

Table 2
Information on included studies (science process skills)

Thesis No	*Thesis Type*	*Education Area*	*Sample Group*	*Implementation Period*	*Category of Publication Year*
480171	Master's Degree	Science	University	13-18 Week	1
508639	Master's Degree	Preschool	Preschool	7-12 Weeks	1
541728	Master's Degree	Science	University	7-12 Weeks	1
534407	Master's Degree	Science	Pre-School	7-12 Weeks	1
560886	Master's Degree	Science	Teacher	7-12 Weeks	2
554602	Master's Degree	Science	Secondary School	7-12 Weeks	2
540966	Master's Degree	Science	Primary School	7-12 Weeks	2
565415	Master's Degree	Pre-School	Pre-School	13-18 Week	2
552833	Master's Degree	Science	Secondary School	1-6 Weeks	2
592742	Master's Degree	Science	Secondary School	1-6 Weeks	2
561644	PhD	Science	Secondary School	1-6 Weeks	2
570443	Master's Degree	Pre-School	Pre-School	7-12 Weeks	2
575624	Master's Degree	Science	Pre-school	7-12 Weeks	2
629972	PhD	Science	Pre-school	7-12 Weeks	2
618883	PhD	Preschool	Pre-school	7-12 Weeks	2
620030	Master's Degree	Science	Secondary School	7-12 Weeks	2
676732	Master's Degree	Pre-School	Pre-school	7-12 Weeks	3
691093	Master's Degree	Preschool	Pre-school	7-12 Weeks	3
713933	Master's Degree	Science	University	13-18 Week	3
671981	Master's Degree	Science	Pre-school	1-6 Weeks	3
753391	Master's Degree	Science	Pre-school	1-6 Weeks	3
754464	Master's Degree	Science	Secondary School	1-6 Weeks	3

When the literature on meta-analysis is examined, it is stated that the average effect size is calculated by the fixed effect model and random effects model (Borenstein, Hedges, Higgins, & Rothstein, 2009; Şen & Yıldırım, 2020). To determine according to which model the average effect size of the studies included in the research will be calculated, it is decided by heterogeneity test (Şen & Yıldırım, 2020). If the p-value of the heterogeneity test is less than 0.05 or greater than the df value in the table, it indicates that each study included in the analysis has a heterogeneous structure. In other words, individual studies do not have the same structure. In these conditions, the overall effect should be calculated using the random effect model. In these conditions, the overall effect should be calculated using the random effect model. In this case, the p value of the heterogeneity test is greater than 0.05 or the Q value in the table is smaller than the df value, indicating that each study included in the analysis has a homogeneous structure. In other words, the structure of the individual studies is similar. Under these conditions, the overall effect should be calculated using the fixed effect model.

2.6. Investigation of Publication Bias

Although the studies included in the meta-analysis are obtained carefully, the bias in the studies will cause the main effect size to be affected by this bias. Many studies show that studies with high effect sizes are more likely to be published than studies with lower effect sizes (Dinçer, 2014). Since this meta-analysis consists mostly of published studies, it will also witness some biases in the literature. In this case, it means publication bias.

To avoid any bias in the answers to the questions sought in the problem and sub-problems, funnel plot and Classic fail-safe N statistic were used in the meta-analysis study. The funnel scatter plot shows the effect size (ES) on the X-axis, the standard error of the study (SEM) on the Y-axis, and the probability of publication bias (Cooper, Hedges, & Valentine, 2009). In the absence of publication bias, individual studies should be symmetrical as well as the effect size. For a better interpretation of the funnel scatter plot, the symmetry values of the studies outside the funnel according to effect size are also presented. Although the funnel scatter plot makes some claims about publication bias, it cannot give a clear and definite result. Classic fail-safe N statistic was used for a clear result. The Classic fail-safe N statistic indicates the amount of work required to neutralise the effect. While the calculation of this value in a few studies (such as 5-10) indicates that there is publication bias, on the contrary, a very high number of values (from 1000 to 3000) indicates that there is no publication bias.

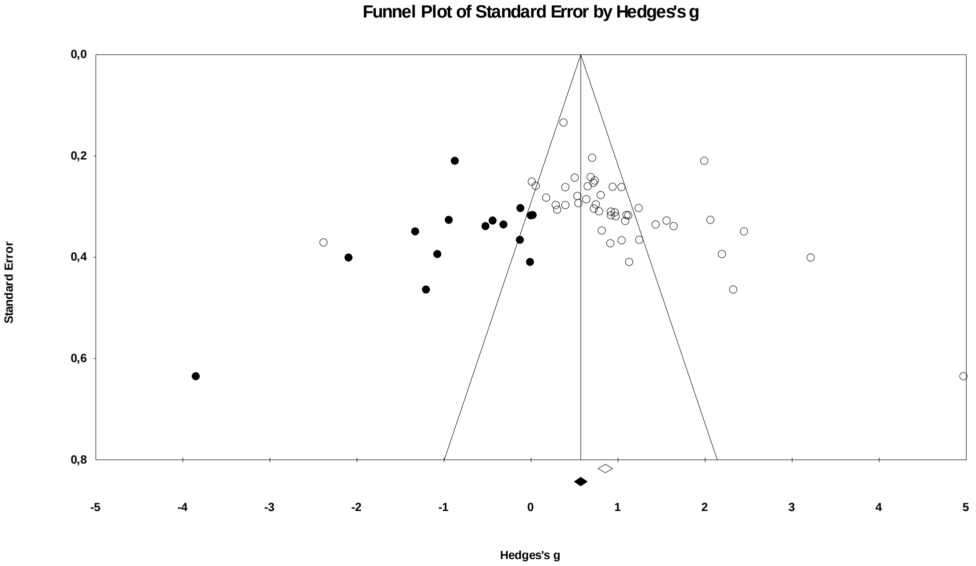
3. Findings

3.1. Findings related to Publication Bias Regarding the Effect of STEM Applications on Academic Achievement

Before calculating the overall effect size with meta-analysis, a publication bias test was performed, and the funnel scatter plot obtained is presented in Figure 2.

The funnel scatter plot shows that their symmetries according to the effect size do not overlap with the studies to the left of the effect size. Due to this situation, the study is considered to have publication bias. In addition to this situation, Classic fail-safe N was calculated as 5562. That is, 5562 additional studies are needed to reach almost zero significance level. The number of individual studies included in the study is 47 and it is not possible to reach 5562 studies other than these studies. This means that there is no publication bias in the study.

Figure 2
Funnel scatter plot for broadcast bias



After determining that there was no publication bias in the studies, the effect sizes of each study are shown in Table 3.

Table 3
Effect size of the studies included in the research

Name of the Study	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
562872_01	4.981	0.637	0.406	3.732	6.230	7.815	0.000
583364_01	3.226	0.403	0.162	2.436	4.015	8.006	0.000
583364_03	2.460	0.351	0.123	1.771	3.148	7.000	0.000
672056_01	2.336	0.466	0.217	1.423	3.249	5.013	0.000
498288_01	2.206	0.396	0.157	1.429	2.982	5.569	0.000
583364_02	2.074	0.328	0.108	1.430	2.718	6.315	0.000
533367_01	2.004	0.212	0.045	1.589	2.419	9.463	0.000
552833_01	1.652	0.341	0.116	0.984	2.320	4.848	0.000
527233_02	1.571	0.330	0.109	0.924	2.218	4.761	0.000
527233_01	1.446	0.338	0.114	0.784	2.107	4.282	0.000
641693_02	1.257	0.368	0.135	0.535	1.978	3.415	0.001
620030_01	1.251	0.305	0.093	0.653	1.849	4.099	0.000
573011_01	1.141	0.411	0.169	0.334	1.947	2.772	0.006
556449_01	1.131	0.320	0.102	0.504	1.758	3.538	0.000
556449_02	1.110	0.319	0.102	0.485	1.735	3.482	0.000
541728_01	1.095	0.331	0.109	0.447	1.744	3.311	0.001
644523_01	1.054	0.369	0.136	0.331	1.777	2.857	0.004
635609_01	1.053	0.264	0.070	0.535	1.570	3.989	0.000
643390_01	0.985	0.321	0.103	0.355	1.615	3.066	0.002
556449_04	0.975	0.314	0.098	0.360	1.590	3.107	0.002
713933_01	0.951	0.263	0.069	0.435	1.467	3.614	0.000
600005_01	0.932	0.320	0.102	0.305	1.559	2.915	0.004
530773_01	0.930	0.312	0.098	0.318	1.542	2.980	0.003
743510_01	0.924	0.375	0.140	0.190	1.659	2.466	0.014
641693_01	0.827	0.350	0.122	0.141	1.512	2.365	0.018
755826_01	0.814	0.279	0.078	0.266	1.362	2.913	0.004
527233_03	0.796	0.312	0.097	0.185	1.406	2.554	0.011
527233_04	0.758	0.298	0.089	0.174	1.341	2.544	0.011
527021_02	0.747	0.251	0.063	0.255	1.238	2.979	0.003
556449_03	0.736	0.306	0.094	0.135	1.336	2.402	0.016
467613_01	0.732	0.255	0.065	0.231	1.233	2.866	0.004
572881_01	0.716	0.206	0.042	0.312	1.119	3.476	0.001
621137_01	0.698	0.244	0.059	0.220	1.176	2.864	0.004
568332_01	0.664	0.262	0.069	0.151	1.178	2.536	0.011

Table 3 continued

Name of the Study	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
509021_01	0.649	0.288	0.083	0.085	1.213	2.254	0.024
510413_01	0.558	0.296	0.087	−0.022	1.138	1.887	0.059
506210_01	0.546	0.281	0.079	−0.005	1.098	1.941	0.052
527021_01	0.516	0.245	0.060	0.036	0.996	2.105	0.035
490625_01	0.408	0.299	0.090	−0.178	0.995	1.364	0.173
546488_01	0.408	0.264	0.070	−0.110	0.926	1.545	0.122
546356_01	0.387	0.136	0.019	0.119	0.654	2.836	0.005
510413_02	0.314	0.308	0.095	−0.290	0.918	1.018	0.309
522774_01	0.298	0.299	0.089	−0.288	0.884	0.996	0.319
772819_01	0.189	0.285	0.081	−0.369	0.746	0.663	0.507
546488_02	0.068	0.261	0.068	−0.444	0.580	0.260	0.795
660696_01	0.022	0.253	0.064	−0.474	0.518	0.087	0.931
628340_01	−2.370	0.373	0.139	−3.101	−1.639	−6.351	0.000

Table 3 presents the effect sizes of individual studies with Hedges's g. While the study coded 562872_01 was determined as the study with the highest effect ($g = 4.981$), the study with the lowest effect ($g = -2.370$) was determined as the study coded 628340_01.

The frequency distribution of the effect sizes of the studies included in the meta-analysis in terms of their directions and Thalheimer and Cook’s (2002) classification is presented in Table 4.

Table 4

Frequency distribution table of the directions of effect sizes and Thalheimer and Cook’s (2002) classification

Direction of Effect Size	f	%
Positive	46	97.87
Negative	1	2.13
Zero	0	0
Level of Effect Size		
Insignificant	2	4.26
Low	4	8.52
Moderate	13	27.65
High	13	27.65
Very high	6	12.78
Perfect	9	19.14

When Table 4 was examined, it was determined that the effect size was positive (in favor of the experimental group) in 46 (97.87%) studies, while it was negative (in favor of the control group) in 1 (2.13%) study. According to Thalheimer and Cook's (2002) classification, 2 (4.26%) individual studies had insignificant effect size, 4 (8.52%) individual studies had low effect size, and 13 (27.65%) individual studies had mediate effect size. However, 13 (27.65%) individual studies had a high effect size, 6 (12.78%) individual studies had a very high effect size, and 9 (19.14%) individual studies had a perfect effect size.

To calculate the overall effect because of meta-analysis, a fixed or random effect model is used. To decide which of these two models should be chosen, it is necessary to look at the funnel plot. The funnel plot of 47 individual studies included in the meta-analysis is presented in Figure 3. When Figure 3 is analysed, almost all the individual studies are expected to be within the specified curves. If the individual studies are outside these curve lines, it can be said that the study has a heterogeneous structure. To decide whether a meta-analysis study is heterogeneous or homogeneous, a heterogeneity test should be performed. The results of the heterogeneity test are given in Table 5.

Figure 3

Funnel plot of the distribution of effect sizes according to Hedges' g method

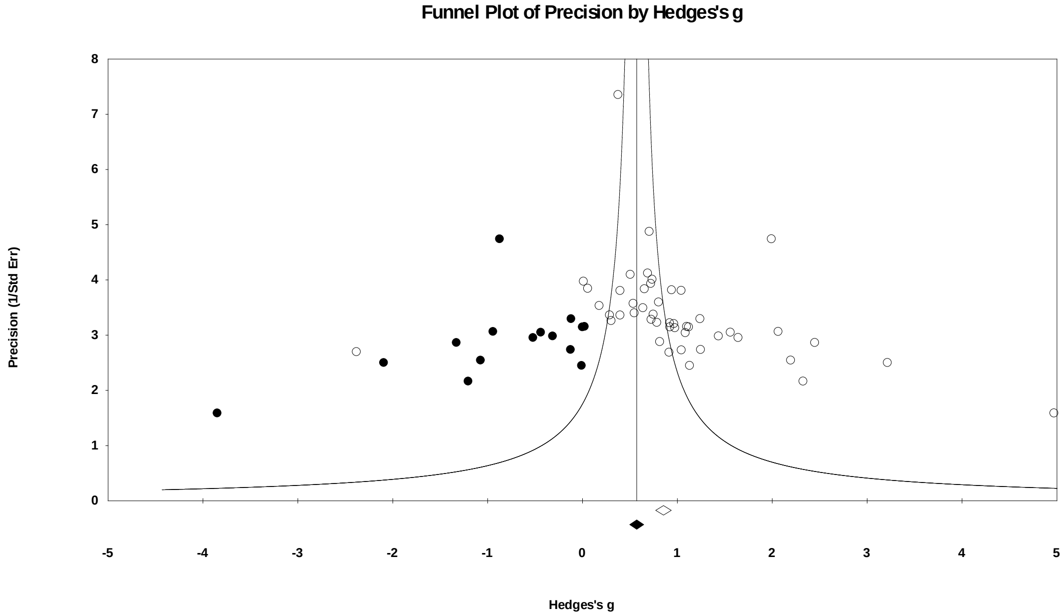


Table 5

Heterogeneity test analysis

Q-value	*df (Q)*	*p-value*	*I-squared*
312.585	46	0.000	85.284

When Table 5 is analysed, it is seen that the p-value is "0.000" and it is less than 0.05. As a result of this, it is determined that individual studies are heterogeneous. In addition, the test of whether the individual studies are heterogeneous should also be checked on the chi-square table. The "Q-value" under the heterogeneity values heading was calculated as 312.585 and the critical value for df(Q)=46 was found as 62.830 in the Chi-square table. It is seen that the Q-value is greater than the critical value. In this case, it means that the studies are heterogeneous. As a result of these calculations, it was determined that the individual studies were heterogeneous.

After determining that the 47 studies included in the meta-analysis were heterogeneous, the overall effect was calculated according to the random effect model, and the results are presented in Table 6.

Table 6

The effect size of STEM implementation on academic achievement according to the random effect model

General Effect Size	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
0.979	0.112	0.012	0.760	1.198	8.767	0.000

When Table 6 is analysed, it is seen that the effect size of the studies is 0.979. The effect size calculated according to Thalheimer and Cook's (2002) classification is determined as high level. The fact that the p-value is less than 0.05 significance value shows that there is a significant difference between the groups. In other words, there is a statistically significant difference between the education conducted with the traditional teaching model and the education in which STEM applications are carried out. According to this result, it was determined that the effect of STEM applications was positive and at a high level by looking at the general effect size ($g = 0.979$) obtained because of the studies combined with the meta-analysis method.

3.2. Findings Regarding the Moderator of Publication Type

The effect of STEM applications on academic achievement has been investigated in master's and doctoral theses. The studies included in the meta-analysis were divided into two groups master's and doctoral theses. To determine whether the random effect model or fixed effect model will be applied for each group, the heterogeneity test results are presented in Table 7.

Table 7
Heterogeneity test results by moderator of publication type

Publication Type	*Q-value*	*df (Q)*	*p-value*	*I-squared*	*Chi-Square Critical Value*	*Impact Model*
PhD	22.734	8	0.004	64.810	15.507	Random
Master's Degree	269.825	37	0.000	86.287	52.192	Random

When Table 7 is examined, it is seen that the general effects of the studies in the doctorate and master's degree categories should be calculated by the random effect model. The results obtained are presented in Table 8.

Table 8
Calculation of the overall effect size of the studies in the publication type category

Publication Type	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
PhD	1.187	0.169	0.029	0.855	1.518	7.018	0.000
Master's Degree	0.934	0.128	0.016	0.683	1.186	7.289	0.000

When Table 8 is analysed, it is seen that the effect size of the studies in the doctorate category is calculated as 1.187. In addition to this, the effect size of the studies in the master's degree category was calculated as 0.934. According to Thalheimer and Cook's (2002) classification, these effect sizes are determined as very high level for the doctoral category and high level for the studies in the master's category.

3.3. Findings Regarding the Moderator of Education Area

The effect of STEM applications on academic achievement was divided into two groups other and science according to the education area. To determine whether the random effect model or fixed effect model will be applied for each group, the heterogeneity test results are presented in Table 9.

Table 9
Heterogeneity test results by moderator of education area

Education Area	*Q-value*	*df (Q)*	*p-value*	*I-squared*	*Chi-Square Critical Value*	*Impact Model*
Other	9.464	4	0.051	57.737	9.489	Fixed
Science	300.141	41	0.000	86.340	56.942	Random

When Table 9 is examined, it is seen that the general effect of the other category should be calculated according to the fixed effect model and the general effect of the studies in the science category should be calculated according to the random effect model. The results obtained are presented in Table 10.

Table 10
Calculation of the overall effect size of the studies in the education area category

Education Area	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
Other	0.628	0.138	0.019	0.358	0.897	4.560	0.000
Science	1.012	0.122	0.015	0.774	1.251	8.310	0.000

When Table 10 is analysed, it is seen that the effect size of the studies in the other category was calculated as 0.628. In addition to this, the effect size of the studies in the science category was calculated as 1.012. According to the classification of Thalheimer and Cook (2002), these effect sizes were determined as medium level for the other category and high level for the studies in the science category.

3.4. Findings Regarding the Moderator of Sample Group

The effect of STEM applications on academic achievement was divided into four groups primary school, secondary school, high school, and prospective teachers according to the sample group. To determine whether the random effect model or fixed effect model will be applied for each group, the heterogeneity test results are presented in Table 11.

Table 11
Heterogeneity test results by moderator of sample group

Sample Group	*Q-value*	*df (Q)*	*p-value*	*I-squared*	*Chi-Square Critical Value*	*Impact Model*
Primary School	80.363	5	0.000	93,778	11.070	Random
Secondary School	190.313	32	0.000	83,186	46.194	Random
High School	25.284	2	0.000	92,090	5.991	Random
Prospective Teachers	2.966	4	0.563	0,00	9.488	Fixed

When Table 11 is examined, it is seen that the general effect size of the studies of STEM applications carried out with primary, secondary, and high school students should be calculated according to the random effect model, while the general effect size of the studies of STEM applications carried out with prospective teachers should be calculated according to the fixed effect model. The findings obtained are presented in Table 12.

Table 12
Calculation of the overall effect size of the studies in the sample group category

Sample Group	*Effect Size*	*Standard Error*	*Varianc e*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
Primary School	0.406	0.524	0.274	−0.620	1.433	0.776	0.438
Secondary School	1.081	0.128	0.016	0.831	1.331	8.472	0.000
High School	1.097	0.473	0.224	0.170	2.025	2.319	0.020
Prospective Teachers	0.818	0.126	0.016	0.572	1.064	6.521	0.000

When Table 12 is examined, it is seen that the effect size of the studies of the students whose category is primary school is 0.406, the effect size of the studies of the students whose category is secondary school is 1.081, the effect size of the studies of the students whose category is high school is 1.097 and the effect size of the studies of the students whose category is prospective teachers is 0.818. According to the classification of Thalheimer and Cook (2002), it was determined that primary school students were at a medium level, secondary school students were at a high level, high school students were at a high level and the category of prospective teachers was at a high level.

3.5. Findings Regarding the Moderator of Implementation Period

The effect of STEM applications on academic achievement was divided into three groups 1-6 weeks, 7-12 weeks, and 13-18 weeks according to the implementation period. To determine whether the random effect model or fixed effect model will be applied for each group, the heterogeneity test results are presented in Table 13.

Table 13

Heterogeneity test results by moderator of implementation period

Implementation Period	*Q-value*	*df (Q)*	*p-value*	*I-squared*	*Chi-Square Critical Value*	*Impact Model*
1-6 Weeks	196.549	23	0.000	88.298	35.172	Random
7-12 Weeks	93.316	17	0.000	81.782	27.587	Random
13-18 Week	1.036	4	0.904	0.000	9.488	Fixed

When Table 13 is examined, it is understood that the overall effect size of the studies with an implementation period of 1-6 weeks and 7-12 weeks should be calculated according to the random effect model, and the overall effect size of the studies with an implementation period of 13-18 weeks should be calculated according to the fixed effect model. The results obtained are presented in Table 14.

Table 14

Calculation of the overall effect size of the studies in the implementation period category

Implementation Period	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
1-6 Weeks	0.793	0.164	0.027	0.471	1.114	4.836	0.000
7-12 Weeks	1.239	0.179	0.032	0.888	1.590	6.924	0.000
13-18 Week	0.974	0.135	0.018	0.710	1.239	7.217	0.000

When Table 14 is examined, it is seen that the effect size of the studies with a category of 1-6 weeks is 0.793, the effect size of the studies with a category of 7-12 weeks is 1.239, and the effect size of the studies with a category of 13-18 weeks is 0.974. According to the classification of Thalheimer and Cook (2002), it was determined that studies with an implementation period of 1-6 weeks were high, studies with an implementation period of 7-12 weeks were very high, and studies with an implementation period of 13-18 weeks were at a high level.

3.6. Findings Regarding the Moderator of the Category of Publication Year

The effect of STEM practices on academic achievement was divided into three groups 1 (2017-2018), 2 (2019-2020), and 3 (2021-2022) according to the category of publication year. To determine whether the random effect model or fixed effect model will be applied for each group, the heterogeneity test results are presented in Table 15.

Table 15

Heterogeneity test results by moderator of the category of publication year

Category of Publication Year	*Q-value*	*df (Q)*	*p-value*	*I-squared*	*Chi-Square Critical Value*	*Impact Model*
1 (2017-2018)	62.774	16	0.000	74.512	26.296	Random
2 (2019-2020)	222.560	23	0.000	89.666	35.172	Random
3 (2021-2022)	24.068	5	0.000	79.226	11.070	Random

When Table 15 is examined, it is understood that the random effect model should be used when calculating the overall effect sizes of studies with the category of publication year 1 (2017-2018), 2 (2019-2020), and 3 (2021-2022). The findings obtained are presented in Table 16.

Table 16

Calculation of the overall effect size of the studies in the publication year category

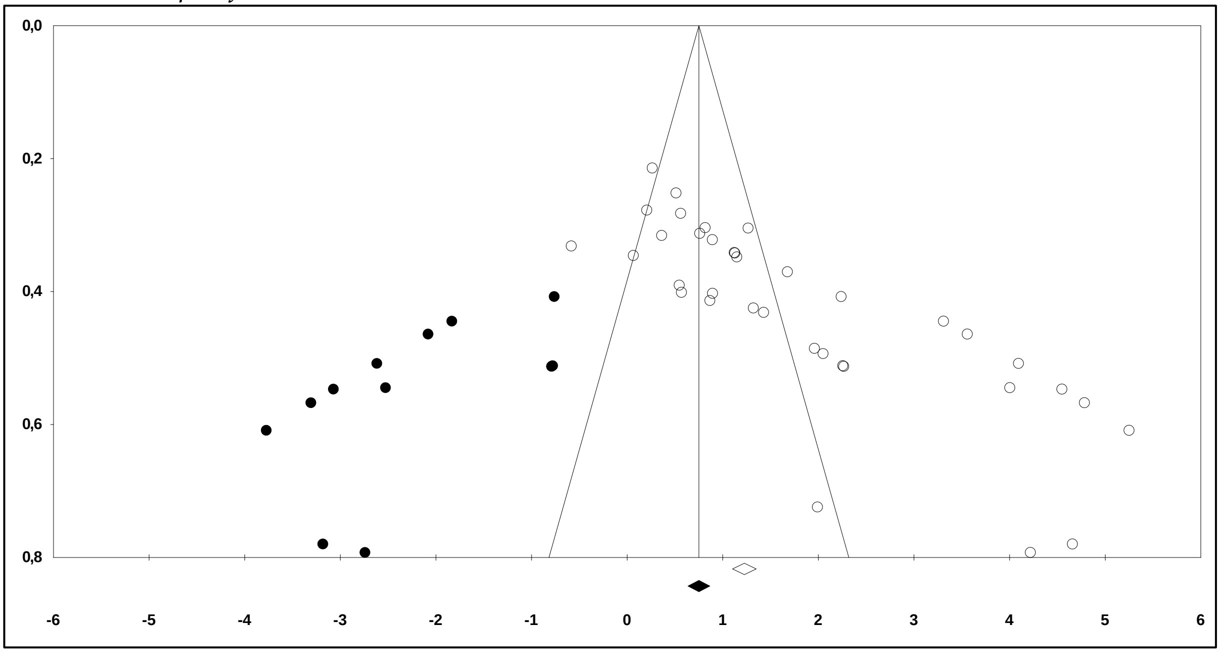
Category of Publication Year	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
1 (2017-2018)	0.904	0.140	0.020	0.630	1.178	6.463	0.000
2 (2019-2020)	1.088	0.187	0.035	0.721	1.454	5.822	0.000
3 (2021-2022)	0.804	0.275	0.076	0.266	1.343	2.927	0.003

When Table 16 is examined, it is seen that the effect size of the studies with category 2017-2018 is 0.904, the effect size of the studies with category 2019-2020 is 1.088, and the effect size of the studies with category 2021-2022 is 0.804. According to the classification of Thalheimer and Cook (2002), it was determined that the studies with the category 2017-2018 were high, the studies with the category 2019-2020 were high, and the studies with the category 2021-2022 were high.

3.7. Findings Related to Publication Bias Regarding the Effect of STEM Applications on Scientific Process Skills

In the meta-analysis process, a publication bias test is performed before looking at the effect sizes of individual studies. The funnel scatter plot, which helps to decide on publication bias, is given below.

Figure 4
Funnel scatter plot for broadcast bias



The funnel scatter plot shows that the symmetries according to the effect size do not overlap with the studies to the left of the effect size. Due to this situation, the study is considered to have publication bias. In addition to this, the Classic fail-safe N was calculated as 4962. That is, 4962 additional studies are needed to reach almost zero significance level. The number of individual studies included in the study is 22 and it is not possible to reach 4962 studies other than these studies. This means that there is no publication bias in the study.

After determining that there was no publication bias in the studies, the effect sizes of each study are shown in Table 17.

Table 17
Effect size of the studies included in the research

Name of the Study	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
570443_01	5.262	0.610	0.373	4.065	6.459	8.619	0.000
570443_05	4.796	0.569	0.324	3.680	5.911	8.427	0.000
575624_01	4.670	0.782	0.611	3.138	6.202	5.975	0.000
570443_04	4.560	0.549	0.301	3.485	5.635	8.313	0.000
671981_01	4.230	0.794	0.631	2.674	5.787	5.326	0.000
570443_02	4.106	0.510	0.260	3.107	5.105	8.054	0.000
565415_01	4.015	0.546	0.299	2.944	5.086	7.348	0.000
570443_03	3.570	0.466	0.217	2.657	4.483	7.663	0.000
570443_06	3.322	0.446	0.199	2.447	4.196	7.442	0.000

Table 17 continued

Name of the Study	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
575624_04	2.278	0.514	0.265	1.270	3.286	4.429	0.000
575624_02	2.267	0.513	0.264	1.261	3.273	4.416	0.000
754464_01	2.251	0.409	0.168	1.449	3.053	5.499	0.000
575624_06	2.062	0.495	0.245	1.092	3.032	4.166	0.000
676732_01	2.003	0.726	0.527	0.580	3.426	2.760	0.006
575624_05	1.972	0.487	0.237	1.017	2.927	4.046	0.000
618883_01	1.688	0.372	0.138	0.959	2.418	4.539	0.000
508639_01	1.440	0.433	0.188	0.591	2.289	3.324	0.001
508639_04	1.333	0.427	0.182	0.497	2.169	3.124	0.002
620030_01	1.278	0.306	0.094	0.677	1.878	4.171	0.000
534407_01	1.159	0.350	0.122	0.474	1.845	3.314	0.001
629972_01	1.139	0.344	0.118	0.465	1.813	3.313	0.001
618883_02	1.133	0.343	0.118	0.460	1.805	3.301	0.001
508639_02	0.906	0.404	0.164	0.113	1.698	2.239	0.025
541728_01	0.904	0.324	0.105	0.269	1.539	2.792	0.005
575624_03	0.878	0.415	0.173	0.064	1.692	2.114	0.035
552833_01	0.828	0.306	0.093	0.229	1.427	2.709	0.007
540966_01	0.772	0.314	0.099	0.156	1.388	2.457	0.014
691093_01	0.581	0.403	0.162	-0.209	1.370	1.441	0.150
480171_01	0.572	0.284	0.081	0.015	1.129	2.013	0.044
508639_03	0.557	0.392	0.154	-0.211	1.326	1.422	0.155
713933_01	0.524	0.253	0.064	0.027	1.021	2.066	0.039
554602_01	0.373	0.317	0.101	-0.249	0.996	1.176	0.240
561644_01	0.276	0.216	0.047	-0.148	0.699	1.276	0.202
560886_01	0.218	0.279	0.078	-0.329	0.765	0.781	0.435
592742_01	0.077	0.347	0.121	-0.604	0.758	0.222	0.824
753391_01	-0.571	0.333	0.111	-1.225	0.082	−1.715	0.086

Table 17 presents the effect sizes of individual studies with Hedges's g. When the effect sizes are analysed, it is seen that the study coded 570443_01 was determined as the study with the highest effect ($g = 5.262$). However, the study with the lowest effect ($g = -0.571$) was determined as the study coded 753391_01. The frequency distribution of the effect sizes of the studies included in the meta-analysis and Thalheimer and Cook's (2002) classification is presented in Table 18.

Table 18

Frequency distribution table of the directions of effect sizes and Thalheimer and Cook's (2002) classification

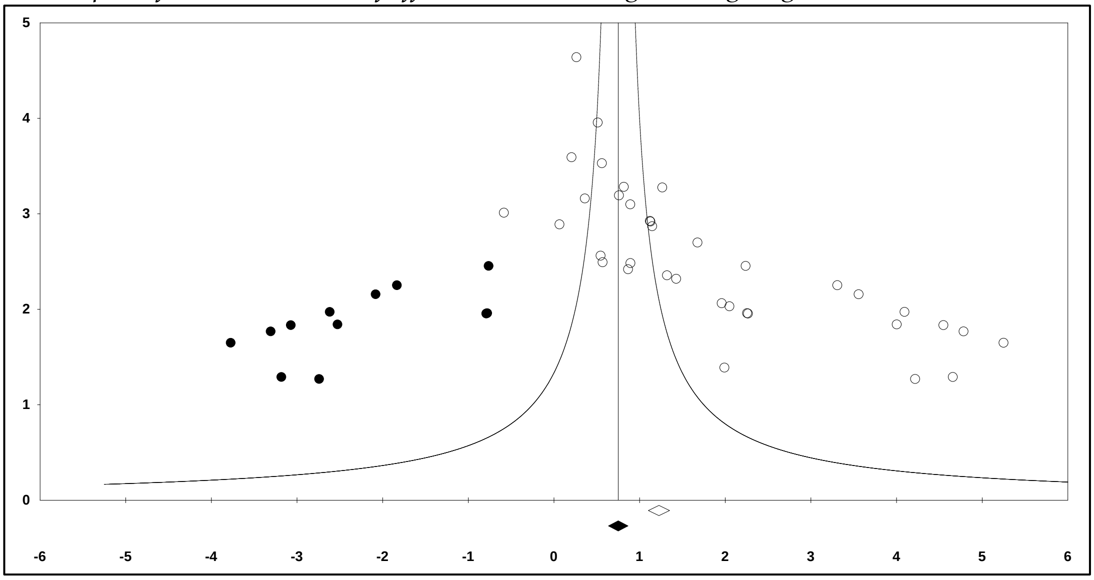
Direction of Effect Size	f	%
Positive	35	97.22
Negative	1	2.78
Zero	0	0
Level of Effect Size		
Insignificant	1	2.78
Low	3	8.34
Moderate	6	16.68
High	4	11.12
Very high	6	16.68
Perfect	16	44.48

When Table 18 was examined, it was determined that the effect size was positive (in favour of the experimental group) in 35 (97.22%) studies, while it was negative (in favour of the control group) in 1 (2.78%) study. According to Thalheimer and Cook's (2002) classification, 1 (2.78%) individual study had an insignificant effect size, 3 (8.34%) individual studies had a low effect size, and 6 (16.68%) individual studies had a moderate effect size. However, 4 (11.12%) individual studies had a high effect size, 6 (16.68%) individual studies had a very high effect size, and 16 (44.48%) individual studies had a perfect effect size.

There are two approaches to calculate the overall effect because of meta-analysis. To decide which of these approaches should be chosen, the funnel plot should be analysed. The funnel plot of 36 individual studies included in the meta-analysis is Figure 5.

Figure 5

Funnel plot of the distribution of effect sizes according to Hedges' g method



When Figure 5 is analysed, the funnel graph of individual studies is given. Almost all the individual studies are expected to be within the specified curves. If the individual studies are not within these curve lines, it can be said that the study has a heterogeneous structure. To decide whether a meta-analysis study is heterogeneous or homogeneous, a heterogeneity test should be performed. The results of the heterogeneity test are given in Table 19.

Table 19

Heterogeneity test analysis

Q-value	*df (Q)*	*p-value*	*I-squared*
386.163	35	0.000	90.936

When Table 19 is analysed, it is seen that the p-value is "0.000" and it is less than 0.05. As a result of this, it is determined that individual studies are heterogeneous. In addition, the test of whether the individual studies are heterogeneous should also be checked on the chi-square chart. The "Q-value" under the heterogeneity values heading was calculated as 386.163 and the critical value for df(Q)=35 was found as 49.802 in the Chi-square table. It is seen that the Q-value is greater than the critical value. In this case, it means that the studies are heterogeneous. As a result of these calculations, it was determined that the individual studies were heterogeneous.

After determining that the 36 studies included in the meta-analysis were heterogeneous, the overall effect was calculated according to the random effect model, and the results are presented in Table 20.

Table 20

Effect size of STEM implementation on academic achievement according to random effect model

General Effect Size	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
1.781	0.214	0.046	1.362	2.201	8.322	0.000

When Table 20 is analysed, it is seen that the effect size of the studies is 1.781. The effect size calculated according to the classification of Thalheimer and Cook (2002) is determined as an excellent level. The fact that the p-value is less than 0.05 significance value indicates that there is a significant difference between the groups. In other words, there is a statistically significant difference between the education conducted with the traditional teaching model and the education in which STEM applications are carried out. According to this result, it was determined that the effect of STEM applications on science process skills was positive and at a perfect level by looking at the overall effect size ($g = 1.781$) obtained because of the studies combined with the meta-analysis method.

3.8. Findings Regarding the Moderator of Publication Type

The effect of STEM applications on science process skills was investigated in master's and doctoral theses. The studies included in the meta-analysis were divided into two groups master's and doctoral theses. To determine whether the random effect model or fixed effect model will be applied for each group, the heterogeneity test results are presented in Table 21.

Table 21
Heterogeneity test results by moderator of publication type

Publication Type	*Q-value*	*df (Q)*	*p-value*	*I-squared*	*Chi-Square Critical Value*	*Impact Model*
PhD	13.492	3	0.004	77.764	7.815	Random
Master's Degree	363.453	31	0.000	91.471	44.985	Random

When Table 21 is examined, it is seen that the general effects of the studies in the doctorate and master's degree categories should be calculated by the random effect model. The results obtained are presented in Table 22.

Table 22
Calculation of the overall effect size of the studies in the publication type category

Publication Type	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
PhD	1.017	0.331	0.110	0.369	1.666	3.074	0.002
Master's Degree	1.890	0.243	0.059	1.413	2.367	7.765	0.000

When Table 22 is examined, it is seen that the effect size of the studies in the doctorate category is calculated as 1.017. In addition to this, the effect size of the studies in the master's degree category was calculated as 1.890. According to Thalheimer and Cook's (2002) classification, these effect sizes are determined as very high for the doctoral category and perfect for the studies in the master's category.

3.9. Findings Regarding the Moderator of Education Area

The effect of STEM applications on science process skills was divided into two groups other and science according to the education area. To determine whether the random effect model or fixed effect model will be applied for each group, the heterogeneity test results are presented in Table 23.

Table 23
Heterogeneity test results by moderator of education area

Education Area	*Q-value*	*df (Q)*	*p-value*	*I-squared*	*Chi-Square Critical Value*	*Impact Model*
Other	124.007	20	0.000	83.872	31.410	Random
Science	167.221	14	0.000	91.628	23.685	Random

When Table 23 is analysed, it is seen that the general effect of other and science categories should be calculated according to the random effect model. The results obtained are presented in Table 24.

Table 24
Calculation of the overall effect size of the studies in the education area category

Education Area	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
Other	1.170	0.193	0.037	0.791	1.548	6.058	0.000
Science	2.580	0.408	0.167	1.779	3.380	6.316	0.000

When Table 24 is analysed, it is seen that the effect size of the studies in the other category was calculated as 1.170. In addition to this, the effect size of the studies in the science category was calculated as 2.580. According to Thalheimer and Cook's (2002) classification, these effect sizes were determined as very high for the other category and perfect for the studies in the science category.

3.10. Findings Regarding the Moderator of Sample Group

The effect of STEM applications on science process skills was divided into four groups primary school, secondary school, high school, and prospective teachers according to the sample group. To determine whether the random effect model or fixed effect model will be applied for each group, the heterogeneity test results are presented in Table 25.

Table 25
Heterogeneity test results by moderator of sample group

Sample Group	*Q-value*	*df (Q)*	*p-value*	*I-squared*	*Chi-Square Critical Value*	*Impact Model*
Primary School	0.000	0	1.000	0.000	-	Fixed
Secondary School	265.446	24	0.000	90.959	36.415	Random
High School	26.208	5	0.000	80.922	11.070	Random
Teachers	0.000	0	1.000	0.000	-	Fixed
Prospective Teachers	0.931	2	0.628	0.000	5.991	Fixed

When Table 25 is examined, it is seen that the general effect size of the studies of STEM applications carried out with secondary school and high school students should be calculated according to the random effect model, while the general effect size of the studies of STEM applications carried out with primary school, teachers and prospective teachers should be calculated according to the fixed effect model. The findings obtained are presented in Table 26.

Table 26
Calculation of the overall effect size of the studies in the sample group category

Sample Group	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
Primary School	0.772	0.314	0.099	0.156	1.388	2.457	0.014
Secondary School	2.311	0.303	0.092	1.717	2.906	7.625	0.000
High School	0.814	0.288	0.083	0.250	1.377	2.828	0.005
Teachers	0.218	0.279	0.078	-0.329	0.765	0.781	0.435
Prospective Teachers	0.636	0.163	0.027	0.316	0.957	3.896	0.000

When Table 26 is examined, it is seen that the effect size of the studies of students whose category is primary school is 0.772, the effect size of the studies of students whose category is secondary school is 2.311, and the effect size of the studies of students whose category is high school is 0.814. In addition to this, while the overall effect size of the studies conducted with teachers was calculated as 0.218, the overall effect size of the studies conducted with prospective teachers was calculated as 0.636. According to the classification of Thalheimer and Cook (2002), the effect of STEM applications on scientific process skills was determined as low in the teacher category, medium in the primary school and prospective teachers categories, high in the high school category, and perfect in the secondary school category.

3.11. Findings Regarding the Moderator of Implementation Period

The effect of STEM applications on scientific process skills was divided into three groups 1-6 weeks, 7-12 weeks, and 13-18 weeks according to the implementation period. To determine whether the random effect model or fixed effect model will be applied for each group, the heterogeneity test results are presented in Table 27.

Table 27
Heterogeneity test results by moderator of implementation period

Implementation Period	*Q-value*	*df (Q)*	*p-value*	*I-squared*	*Chi-Square Critical Value*	*Impact Model*
1-6 Weeks	36.029	2	0.000	94.449	5.991	Random
7-12 Weeks	54.335	5	0.000	90.798	11.070	Random
13-18 Week	250.674	26	0.000	89.628	38.885	Random

When Table 27 is examined, it is understood that the overall effect size of the studies with an implementation period of 1-6 weeks, 7-12 and 13-18 weeks should be calculated according to the random effect model. The results obtained are presented in Table 28.

Table 28
Calculation of the overall effect size of the studies in the implementation period category

Implementation Period	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
1-6 Weeks	1.620	0.817	0.667	0.019	3.221	1.983	0.047
7-12 Weeks	1.008	0.466	0.217	0.095	1.922	2.164	0.030
13-18 Week	1.971	0.247	0.061	1.486	2.455	7.965	0.000

When Table 28 is examined, it is seen that the effect size of the studies with a category of 1-6 weeks is 1.620, the effect size of the studies with a category of 7-12 weeks is 1.008, and the effect size of the studies with a category of 13-18 weeks is 1.971. According to the classification of Thalheimer and Cook (2002), it was determined that the studies with 7-12 weeks were at a high level, and the studies with 1-6 weeks and 13-18 weeks were at a perfect level.

3.12. Findings Regarding the Moderator of the Category of Publication Year

The effect of STEM applications on scientific process skills was divided into three groups 1 (2017-2018), 2 (2019-2020), and 3 (2021-2022) according to the category of publication year. To determine whether the random effect model or fixed effect model will be applied for each group, the heterogeneity test results are presented in Table 29.

Table 29
Heterogeneity test results by moderator of the category of publication year

Category of Publication Year	*Q-value*	*df (Q)*	*p-value*	*I-squared*	*Chi-Square Critical Value*	*Impact Model*
1 (2017-2018)	5.201	6	0.518	0.000	12.592	Fixed
2 (2019-2020)	307.157	22	0.000	92.838	33.924	Random
3 (2021-2022)	52.314	5	0.000	90.442	11.070	Random

When Table 29 is examined, it is understood that the random effect model should be used when calculating the fixed effect sizes of the studies with the category of publication year of 1(2017-2018) and the overall effect sizes of the studies with the category of publication year of 2(2019-2020) and 3(2021-2022). The findings obtained are presented in the table below.

Table 30
Calculation of the overall effect size of the studies in the publication year category

Category of Publication Year	*Effect Size*	*Standard Error*	*Variance*	*Lower Limit*	*Upper Limit*	*Z-Value*	*p-Value*
1 (2017-2018)	0.922	0.137	0.019	0.654	1.189	6.743	0.000
2 (2019-2020)	2.164	0.304	0.093	1.567	2.761	7.108	0.000
3 (2021-2022)	1.364	0.551	0.304	0.284	2.444	2.475	0.013

When Table 30 is examined, it is seen that the effect size of the studies with category 2017-2018 is 0.922, the effect size of the studies with category 2019-2020 is 2.164, and the effect size of the studies with category 2021-2022 is 1.364. According to the classification of Thalheimer and Cook (2002), it was determined that the studies with the category 2017-2018 were high, the studies with the category 2019-2020 were perfect, and the studies with the category 2021-2022 were very high.

4. Discussion, Conclusion and Recommendations

Within the framework of the criteria determined in the study process, 35 theses examining the effect of academic achievement and 22 theses examining scientific process skills were included in the analysis. Within the framework of the general evaluation, it was determined that the effect of STEM education practices on academic achievement was at a high level and the effect on scientific process skills was at a perfect level. The discussion on this determination is presented below under two headings.

4.1. The Effect of STEM Applications on Academic Achievement

Among the theses included in the study, it was determined that the studies examining the effect of STEM applications on academic achievement had a heterogeneous structure. Concordantly, individual studies were analysed according to the random effects model. According to the random effects model, the overall effect size of the studies was calculated as 0.979. This value shows that the average effect size of the theses included in the study is at a high level according to Thalheimer and Cook's (2002) classification. In other words, there is a statistically significant difference between the education conducted with the traditional teaching model and the education in which STEM applications are carried out. According to this result, the overall effect size ($g = 0.979$) obtained as a result of the studies combined with the meta-analysis method indicates that the effect of STEM applications is positive and at a high level.

In the study, the effect of STEM applications on academic achievement according to the moderator of publication type was investigated. In this direction, it was determined that master's and doctoral thesis studies had a heterogeneous structure. Concordantly, individual studies were analysed according to the random effects model. According to the random effects model, the effect size of master's theses and doctoral theses was calculated as 0.934 and 1.187, respectively. According to the classification of Thalheimer and Cook (2002), the average effect size of master's theses is at a high level, and for doctoral theses, it is at a very high level. The fact that the effect size values for both moderators are positive indicates that both master's and doctoral studies are in favour of the experimental group. In this direction, it can be stated that master's and doctoral theses in which STEM applications are carried out have a positive effect on academic achievement.

In another part of the study, the effect of STEM applications on academic achievement was examined according to the moderator of education area. In this direction, it was concluded that the studies in the field of science had a heterogeneous structure, while the studies in other fields were homogeneously distributed. While the effect size of the science field with a heterogeneous structure was 1.012, the effect size of other fields was calculated as 0.628. According to the classification of Thalheimer and Cook (2002), the average effect size of the field of science is at a high level, while the average effect size of other fields is at a medium level. Similarly, in a study conducted by Bergkvist et al. (2012) in Sweden, it was concluded that students who received STEM education were more successful in science education. The result obtained by Bergkvist et al. (2012) supports the result of this study for the education area moderator.

In the study, the effect of STEM applications on academic achievement was investigated according to the sample group moderator. In this direction, it was determined that the studies conducted for primary, secondary, and high school levels had a heterogeneous structure and the studies conducted for prospective teachers had a homogeneous structure. Concordantly, individual studies with a heterogeneous structure were analysed according to the random effects model. According to the random effects model, the effect size of the primary school level was calculated as 0.406, the effect size of the secondary school level as 1.081, the effect size of the high school level as 1.097, and the effect size of the studies conducted for prospective teachers as 0.818. According to Thalheimer and Cook's (2002) classification, it was concluded that the average effect size of the studies conducted at the primary school level was at the medium level, while the effect sizes of the studies conducted for secondary school, high school levels, and prospective teachers were at a high level. As a result, the positive effect size values for all four moderators indicate that the studies conducted at primary, secondary, high school, and prospective teachers levels are in favour of the experimental group. In this direction, it can be concluded that STEM applications positively affect academic achievement at all levels of education. This situation contains supportive results with the report titled "Successful K-12 STEM Education" published by the National Research Council (2011). According to the report, it shows that STEM education improves students' scientific and mathematical understanding, increases their problem-solving skills, and directs their interests to these areas from the first grade to the 12th grade. Therefore, it is thought that teaching towards STEM education will increase the academic achievement of students at all levels.

The theses in the study were also analysed according to the moderator of the implementation period. In this direction, it was concluded that the thesis studies conducted within 1-6 weeks and 7-12 weeks of the implementation period were heterogeneous, while the theses conducted within 13-18 weeks of the implementation period had a homogeneous structure. Concordantly, theses conducted with 1-6 weeks and 7-12 weeks duration were analysed according to the random effects model, while theses conducted with 13-18 weeks duration were analysed according to the fixed effects model. According to the random effects model, the effect size of 1-6 weeks was calculated as 0.793; the effect size of 7-12 weeks was calculated as 1.239; and the effect size of 13-18 weeks was calculated as 0.974 according to the fixed effect model. According to the classification of Thalheimer and Cook (2002), the average effect size of the theses conducted with 1-6 weeks and 13-18 weeks duration is at a high level, and for the theses conducted with 7-12 weeks duration, it is at a very high level. Since the effect size values for all three moderators are positive, it can be said that STEM applications positively affect academic achievement in thesis studies carried out in the given implementation periods. In the study, the effect of STEM practices on academic achievement according to the moderator of the publication year was investigated. In this direction, it was determined that the thesis studies conducted in the 2017-2018, 2019-2020, and 2021-2022 implementation years had a heterogeneous structure. Concordantly, individual studies were analysed according to the random effects model. According to the random effects model, the effect size of the studies conducted between 2017-2018 was calculated as 0.904, the effect size of the studies conducted between 2019-2020 was calculated as 1.088, and the effect size of the studies conducted between 2021-2022 was calculated as 0.804. According to the classification of Thalheimer and Cook (2002), it is seen that all of the thesis studies conducted in the 2017-2018, 2019-2020, and 2021-2022 implementation years are at a high level. This situation can be stated that STEM applications have a positive effect on academic achievement according to the categorised years.

As a result, it was observed that there was a positive effect between STEM education and academic achievement in the theses examined within the scope of the study. This result supports many studies in the literature (Bybee, 2010; Freeman et al., 2014; Hidi & Anderson, 1992; Moore, Roehrig, & Park, 2011; Sanders, 2009; Schleicher, 2015). In one of these studies, Moore, Roehrig, and Park (2011) examined how STEM integration is reflected in teachers' perceptions and practices. As a result of the study, Moore, Roehrig, and Park (2011) stated that teachers who implement STEM education show higher academic achievement in the fields of mathematics, science, and engineering.

4.2. The Effect of STEM Applications on Scientific Process Skills

Among the theses included in the study, it was determined that the studies examining the effect of STEM applications on scientific process skills had a heterogeneous structure. Concordantly, individual studies were analysed according to the random effects model. According to the random effects model, the overall effect size of the studies was calculated as 1.781. This value shows that the average effect size of the theses included in the study is at an perfect level according to Thalheimer and Cook's (2002) classification. The fact that the perfect effect size value is positive indicates that the process is in favour of the experimental group. Concordantly, it can be said that the groups in which STEM applications are carried out have a positive effect on scientific process skills (Bybee, 2013; Çakmakçı & Türk, 2010; Fortus et al., 2005; National Research Council, 2012).

According to the moderator of publication type, the effect of STEM applications on scientific process skills was investigated. In this direction, it was determined that master's and doctoral thesis studies had a heterogeneous structure. Concordantly, individual studies were analysed according to the random effects model. According to the random effects model, the effect size of master's theses and doctoral theses was calculated as 1.890 and 1.017, respectively. According to the classification of Thalheimer and Cook (2002), the average effect size of master's theses is at a perfect level, while it is at a high level for doctoral theses. The fact that the effect size values for both moderators are positive indicates that the studies conducted at both master's and doctoral levels are in favour of the experimental group. In this direction, it can be stated that there is a positive effect on scientific process skills in master's and doctoral theses in which STEM applications are carried out.

In the study, the effect of STEM applications on scientific process skills according to the moderator of the field of application was investigated. In this direction, it was determined that the studies in science and other application areas had a heterogeneous structure. Concordantly, individual studies were analysed according to the random effects model. According to the random effects model, the effect size of the theses in the application field of science was calculated as 1.890, while the effect size of the theses in other fields was calculated as 1.170. According to the classification of Thalheimer and Cook (2002), the average effect size of the theses in the application area of science is at a perfect level, while it is at a very high level for the theses in other application areas. The fact that the effect size values for both moderators are positive indicates that the studies conducted in both science and other application areas are in favour of the experimental group. In this direction, it can be stated that there is a positive effect on scientific process skills within the framework of STEM applications in science and other application areas. As a result, it can be said that different learning areas will affect students' science process skills in different dimensions. This situation is like the study conducted by Fortus et al. (2005) in which he examined how design-based science education can improve scientific process skills. Fortus et al. (2005) stated that STEM education provides students with skills such as analytical thinking, problem-solving, and critical evaluation. These skills are related to the fact that the components of STEM education have different focal points.

Within the scope of the study, the effect of STEM applications on scientific process skills was investigated according to the sample group moderator. In this direction, it was determined that the theses carried out in primary school, teacher, and prospective teachers levels were homogeneous. Therefore, the studies in this group were analysed according to the fixed effect model. On the other hand, it was determined that the theses conducted at secondary and Secondary School levels were heterogeneous and, Concordantly, they were analysed according to the random effect model. Accordingly, the effect size of the studies at the teacher level was calculated as 0.218; the effect size of the studies at the pre-service teacher level was 0.636; the effect size of the studies at the primary school level was 0.772; the effect size of the studies at the secondary school level was 0.814; and the effect size of the studies at the secondary school level was 2.311. According to the classification of Thalheimer and Cook (2002), the average effect size of the theses at the teacher level is low, medium for primary school and university, high for high school, and finally, the effect size for the theses at the secondary school level is determined to be at an excellent level. The fact that all of the effect size values obtained from the specified moderators are positive, it is seen that STEM applications have positive contributions to scientific process skills for the experimental group at all levels of education. Similarly, in a study conducted by Bell (2016) in England, it was stated that teachers' perceptions and understandings of STEM can be improved. In the related literature, there is much research related to the effect of STEM education on scientific process skills for educational levels (Akerson, Abd-El-Khalick, & Lederman, 2000; Fortus & Vedder-Weiss, 2014; Lotter, Harwood, & Bonner, 2007; Luft & Roehrig, 2007). Fortus and Vedder-Weiss (2014), one of these studies, investigated the effect of inquiry-based teaching practices on science process skills in STEM education. At the end of his study, he emphasised the importance of teachers' perception of inquiry-based teaching practices and their impact on developing students' scientific process skills.

The theses in the study were also analysed according to the moderator of implementation duration. In this direction, it was determined that the theses with 1-6 weeks, 7-12 weeks, and 13-18 weeks of implementation time were heterogeneous, and for these reasons, the analysis process was carried out according to the random effect size model. As a result of this analysis, the effect size of the theses with 1-6 weeks of implementation time was determined as 1,620; the effect size of the theses with 7-12 weeks of implementation time was determined as 1,008; and the effect size of the theses with 13-18 weeks of implementation time was determined as 1,971. According to the classification of Thalheimer and Cook (2002), the effect size of the studies with 7-12 weeks was determined to be high, and the theses with 1-6 weeks and 13-18 weeks were determined to be at a perfect level. It is seen that the effect size values determined for all categories in the moderator of implementation duration are positive. Therefore, it is seen that the STEM applications process carried out in the thesis studies in all categories according to the implementation period makes a significant contribution to the development of scientific process skills in favour of the experimental group. In the studies conducted on the effect of the moderator of implementation time on scientific process skills in STEM education, it is seen that the process has a positive effect (Kavak, 2018; Schwartz, Lederman, & Crawford, 2004; Tafazoli et al., 2019; Yoon et al., 2014).

Finally, the theses within the scope of the study were analysed in line with the category of publication year moderator. In this direction, it was determined that the theses published in 2017-2018 were homogeneous, while the theses published in 2019-2020 and 2021-2022 were heterogeneous. Theses published in 2017-2018 were analysed according to the fixed effect size model, while theses published in 2019-2020 and 2021-2022 were analysed according to the random effect size model. As a result of this analysis, the effect size of the theses published in 2017-2018 was 0.922; the effect size of the theses published in 2019-2020 was 2.164; and the effect size of the theses published in 2021-2022 was 1.364. According to the classification of Thalheimer and Cook (2002), it was determined that the effect size of the theses published in 2017-2018 was high, the theses published in 2019-2020 were perfect, and the theses published in 2021-2022 were very high. It is seen that the effect size values determined for all categories in the year of publication moderator are positive. Therefore, it can be stated that the STEM applications process carried out in thesis studies in all categories according to the publication year contributed positively to the development of scientific process skills in favour of the experimental group.

In this study, the effects of theses on academic achievement and scientific process skills of STEM education in Turkey were investigated. Based on the result that STEM education positively affects students' academic achievement, some features that the learning environment to be prepared may have can be suggested. These suggestions are that learning environments in which STEM education is applied should have features such as learning based on problem-solving, collaborative learning, encouraging innovation and creativity, giving regular feedback, and using technology and engineering knowledge effectively.

Another result of the study is that STEM education practices positively affect scientific process skills, and, Concordantly, it can be suggested that the characteristics of learning environments for developing these skills should be being based on observation and inquiry, being able to conduct experiments, being supported by modelling and simulation, supporting data analysis and interpretation skills, being focused on cooperation and communication, and including real-world applications.

Within the scope of the study, the language of publication (Turkish or English), compliance with meta-analysis statistics, examining academic achievement or scientific process skills, and the fact that the study was published after 2017 were determined as inclusion criteria. In this direction, the effect of STEM applications on attitudes toward science or mathematics courses, etc. can be investigated. In the literature, there are studies examining the effect of various STEM applications on academic achievement on a unit or subject basis. With the statistical data to be obtained from these studies, unit-based meta-analysis studies on the effect of STEM applications can be conducted.

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