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Empirical Research

A Meta-Analytic Approach for Examining the Effects of STEAM Education Programs in South Korea

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This study was conducted to analyze previous studies that presented the effects of science, technology, engineering, arts, and mathematics (STEAM) education programs in South Korea and to draw a systematic and comprehensive conclusion. A meta-analytic approach was implemented to integrate research findings based on 83 published studies selected from 549 publications. The overall effect size was found to be a medium one. The effect size by publication type was presented in the following order: the master's thesis, the published journal, and the doctoral thesis. The effect size by school grade was presented in the following order: elementary school, middle school, and high school. The effect size by studies applied to gifted students appeared bigger than that applied to general students. The effect size by multidisciplinary type appeared bigger than by interdisciplinary type, while the effect size of gifted education was biggest among various instruction types. The effect size by the subcategories of dependent variables indicated creativity, science process skills, attitude toward science, creative problem solving, academic achievements, and attitudes toward mathematics. A meta-regression analysis was conducted for the continuous variables, and neither publication year nor application period was of significant effect. Taken together, this research demonstrates the effects of STEAM education programs from 2010 to 2014 in South Korea and provide implications regarding the continuation of the programs. For the success of the STEAM education, it is necessary to establish conditions for teachers to accelerate their competence for STEAM education. Also, it would be worthwhile to expand the opportunities of the STEAM education program beyond school curriculums.

Keywords: STEAM education programs, Overall effect size, Effect size, Dependent variables, Meta-regression analysis

INTRODUCTION

In South Korea, science, technology, engineering, arts, and mathematics (STEAM) education has been researched and applied by pilot research schools and in-service teacher societies since 2011. STEAM education, which aims to improve learner interest in learning, creativity, and problem-solving skills, is spreading quickly, and experts have suggested optimistic views on the effects of STEAM education (Lim, 2012).

STEAM programs have been developed and applied in different integration types, class types, and periods, from kindergarten to high school. At first, STEAM education was applied to extracurricular activities such as science camp and science club; but later it was actively adopted into regular classroom curricula (Ham, 2020). While science was a main subject to be implemented, STEAM has been extended to other classes such as art, Korean language, technology, and social studies. As a result, various STEAM programs have been developed and turned out to provide positive educational effects on students' interest, integrated thinking, communication, and creativity (Kang, 2019).

In order to activate the STEAM education in South Korea, government and schools had made various efforts (Kwon et al., 2021). First, for the practice of convergence

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education, various teaching-learning materials needed to be developed. The advanced technology, future vocation and others were used as interesting themes for the instructional guide or contents and they were applied in the classroom. Second, there have been enormous efforts to develop teachers' competence. There are many duty training programs for the teachers in each Metropolitan and Provincial Office of Education and the improving awareness programs for the administrators. Third, we have built a kind of environment to practice STEAM education. The government has provided a financial fund to set up cutting-edge science classroom and maker space for the future education.

Currently, as interest in STEAM education rapidly increases, researchers are actively developing education programs and studying their effects (Jeong & Kim, 2015). Different studies report the effects of STEAM programs, but findings are limited, and they were obtained from various subjects, programs, and class types. These findings have different limitations and, as a result, propose contradictory results (Oh, 2002). Therefore, understanding the effects objectively is limited. It is necessary to draw a conclusion on the subject by integrating the effects of STEAM education programs and analyzing their effect size according to various moderator variables.

Today, researchers access a tremendous amount of research everyday from a number of studies published in different countries and online databases. Meta-analysis is a rational process by which independent individual studies on a certain subject are collected; the data are quantitatively processed using statistical methods, and a new and meaningful conclusion is drawn (Glass et al., 1981). However, caution must be exercised in trusting a generalized conclusion drawn from the meta-analysis of different studies, and the most important issues are whether the research has followed a reasonable and objective process and whether it was conducted with consistency (Park & Shin, 2014).

In this study, meta-analysis was used for investigating the research trends and overall effect size related to STEAM education programs developed and applied in South Korea and the differences in effect size according to variables that influence the effectiveness of the programs. First, the study examined the overall effect size of STEAM education programs, and then it examined the effect size of STEAM education programs according to categorical moderator variables such as publication type, school level, student characteristics, integration type, class type, dependent variables, and continuous moderator variables such as publication year and program period. This study provides an objective comparison of the effects of STEAM education according to different variables, and the trend analysis and meta-analysis results can be used for proposing a new direction for STEAM education. And by examining the effect size according to categorical moderator variables through meta-analysis, implications regarding instructional design could be given.

RESEARCH DESIGN

1. Scope and collection of research subjects

In this study, master's theses, doctoral dissertations, and studies published in academic journals between 2010 and 2014 were chosen as subjects to conduct a meta-analysis of the effects of STEAM education programs. In meta-analysis, it is crucial to search two or more databases simultaneously to collect every paper included in the research subjects (Lee, 2008). In this study, as shown in Table 1, the subject papers were found using different online databases. The Research Information Sharing Service (RISS) of the Korea Education & Research Information Service, the Koreanstudies Information Service System (KISS), the National Assembly Library, the National Digital Science Library (NDSL), an electronic resource metasearch of the Korea National University of Education Library, and Google Scholar were all utilized.

Using keywords like "STEAM," "integrative education," and "STEM," 549 papers which were mostly journal articles or theses were screened. From these, we excluded 254 papers that were not related to STEAM education and 8 papers without originality. In addition, 152 papers without effect size, such as case study, qualitative study and explorative study, were turned down. Another 52 papers were excluded as shown in Fig. 1, and the remaining 83 papers were selected for this study. The subject selection process is presented in Fig. 1. If a master's thesis or a Ph.D. dissertation was later published in peer-reviewed academic journal, only the journal article was taken for the analysis.

Table 1. List of databases used in this study

Database	Website
Research Information Sharing Service (RISS)	https://riss.kr
Koreanstudies Information Service System (KISS)	https://kiss.kstudy.com
National Assembly Library of the Republic of Korea	https://www.nanet.go.kr
National Digital Science Library (NDSL)	http://www.ndsl.kr
e-Resources Meta-Search of KNUE Library	http://lib.knue.ac.kr
Google Scholar	https://scholar.google.co.kr

KNUE = Korea National University of Education.

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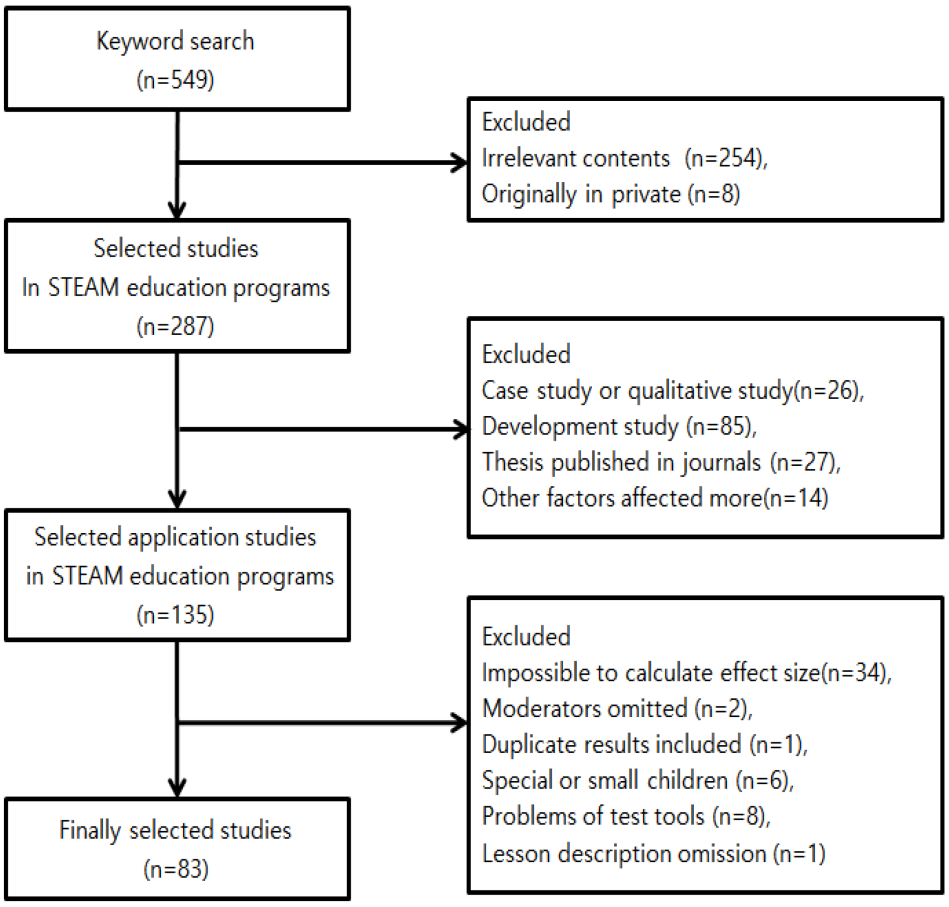


Fig. 1. Strategy for the selection of the studies. STEAM = science, technology, engineering, arts, and mathematics.

2. Coding of characteristic variables in analysis data

For the sub-group analysis, the school level, student characteristics, publication type, integration type, class type, and dependent variables were coded as categorical moderator variables. For the meta-regression analysis, publication year and program period were coded as continuous moderator variables. The coding standard proposed by Cooper (2010) was modified for this study, and information recorded in the coding form included the basic data of the subject studies such as the serial number, research title, publication year, author, and source. In addition, various independent, moderator, and dependent variables such as base school subject, integration type, class type, subject grade, gender, subject characteristics, organization type, program period, and data required for calculating the effect size were included.

According to the criteria proposed by Drake and Burns (2004), the integration types of STEAM education programs were divided by multidisciplinary, interdisciplinary, and transdisciplinary integration. Multidisciplinary integration primarily focuses on academic disciplines and, therefore, selects and organizes contents related to subjects from different independent disciplines. Interdisciplinary integration organizes a curriculum based on the common concepts and functions of several disciplines. It is possible to distinguish disciplines within a curriculum, but the contents from different disciplines are not as important as in the multidisciplinary approach. Lastly, transdisciplinary integration organizes a curriculum based on the questions and interests of learners from the child-centered viewpoint. The three types of integrations are relevant to the types of STEAM education in South Korea.

In the analysis, the class types of STEAM education programs were classified into 5 types inductively (Type 1–Type 5). Type I is an intra-subject class in which elements from science, technology, engineering, art, and mathematics are integrated into a central subject. Type II is an inter-subject class in which different subjects are integrated based on a common theme. Type III refers to a curriculum reorganization based on a theme, and creative experience activities, after-school activities, club activities, and evening self-study are used. Type IV concerns gifted student education operated by unit schools or local offices of education. Finally, Type V is a STEAM

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education performed outside of school.

To examine the effect size by each dependent variable, we selected creativity, science inquiry ability, attitude toward science, creative problem-solving skills, academic achievement, and attitude toward mathematics. Although individual research showed varying effect size, only the dependent variable with more than 5 different effect size was taken into consideration.

Two collaborators performed the coding process based on the developed coding sheet. Instead of showing consistency between the coders by assessing coding reliability, the researchers shared a sufficient discussion to prevent problems related to inconsistency and the reliability of coding during the coding process. Information of the analysis subjects, such as the author, publication year, publication type, school level, integration type, class type, program period, and publication year of the 83 papers are presented in Table 2.

3. Calculation and interpretation of effect size

Meta-analysis refers to calculating the overall effect size using statistical methods to integrate individual study results. When there are a large number of cases, or when different groups are highly homogenous, the mean difference between the two groups is marginal, but a statistically significant difference can be found in the t-test results. In this case, despite the statistical significance, a practical significance may not exist (Baek, 2005). In addition, studies on the same subject may use different scales and methods when reporting their results. To prevent this problem, an effect size shows the difference in the standardized mean values between different groups using a common scale; therefore, results obtained using different scales and methods can be compared meaningfully (Oh, 2002). Subjects in this study were a posttest-only control group, a pretest-posttest control group, or a one-group pretest-posttest design, and different methods for calculating the effect size were applied according to the research design. The method of calculating the effect size is presented in Fig. 2. An effect size smaller than 0.4 was interpreted as small, 4.0 or larger as medium, and 0.8 or larger as large (Cohen, 1998; Hwang, 2014).

The effect size was calculated as the corrected standardized mean difference (Hedges' g) (Cohen, 1998). Cohen's d has a tendency to overestimate effect size when the sample is small; therefore, Hedges' g is required for correction. Moreover, when studies with large samples and small samples are mixed, the samples must be converted to g (Hedges & Olkins, 1985). Here, effect size was analyzed in studies presenting the mean value and standard deviation of two groups or one with t or F value, or one with a difference in mean value between pre- and post- tests.

To calculate the overall average effect size, the weighted average of the effect size must be calculated first. As different studies have different characteristics, weight must be taken into account to calculate the average effect size properly. In general, weight is the inverse number of variance, and larger samples result in larger weights. A weighted effect size is calculated by multiplying individual effect sizes by their weight. An average effect size is calculated by dividing the sum of weight effect sizes by the sum of weights.

In this study, most data analyses, such as the effect sizes and the homogeneity test, were processed using Comprehensive Meta-Analysis (CMA) Version 3.3 (Biostat Inc., Englewood, NJ, USA), which has the advantages of using simpler calculations than other meta-analysis tools and the ability to easily create figures and charts for various meta-analyses.

RESULT AND DISCUSSION

1. Status of subject papers and research trends

Prior to presenting the meta-analysis results based on the effect size, the current trend of STEAM education research was investigated. Although this study is not completely representative of the population because qualitative research and literature reviews were excluded, the overall trends in STEAM program development was examined based on experimental research in which the effect size could be calculated. The total number of subject studies was 83, and 162 effect sizes were calculated. Table 3 shows the trends of STEAM education research in South Korea.

The number of studies in which the effect size of STEAM programs could be calculated was 1 in 2010, 2 in 2011, 13 in 2012, 37 in 2013, and 30 in 2014. The overall interest in STEAM education research is increasing, and the relevant research is expected to increase in the future as pilot schools and teacher societies apply STEAM education in the field.

1) Research trends according to integration types of STEAM education programs

Table 4 presents the research trends according to the integration types of STEAM education programs. Of the entire STEAM program, the multidisciplinary type accounts for 71.1% (59 studies), the interdisciplinary type for 28.9% (24 studies), and transdisciplinary type for 0% (0 studies), which shows a concentration of STEAM programs on the multidisciplinary type. This finding sup-

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Table 2. Characteristics of the selected research for this study

No.	Authors (year)	Publication type	Subject school type	Integration type	Instruction type	Application period (mo)
1	Ahn (2014)	Master's thesis	Elementary	Mutidisciplinary	III	10
2	Bae et al. (2013)	Journal	Elementary	Mutidisciplinary	I	13
3	Bae et al. (2014)	Journal	Elementary	Mutidisciplinary	I	12
4	Bae (2011)	Journal	Middle	Mutidisciplinary	III	30
5	Bak & Kim (2014)	Journal	Elementary	Mutidisciplinary	IV	17
6	Byeon (2010)	Master's thesis	Elementary	Interdisciplinary	I	15
7	Chae & Noh (2013)	Journal	Elementary	Interdisciplinary	I	12
8	Cho (2014a)	Master's thesis	Elementary	Mutidisciplinary	I	8
9	Cho (2014b)	Master's thesis	High	Mutidisciplinary	I	2
10	Choi (2013a)	Master's thesis	Middle	Interdisciplinary	IV	10
11	Choi (2014)	Master's thesis	Middle	Mutidisciplinary	I	15
12	Choi (2013b)	Journal	Middle	Interdisciplinary	III	13
13	Choi & Lee (2013)	Journal	Elementary	Interdisciplinary	II	9
14	Geum & Bae (2012)	Journal	Elementary	Mutidisciplinary	III	12
15	Heo (2013)	Master's thesis	Elementary	Mutidisciplinary	I	11
16	Heo (2014a)	Master's thesis	High	Interdisciplinary	IV	20
17	Heo (2014b)	Master's thesis	Elementary	Interdisciplinary	I	18
18	Im (2012)	Master's thesis	Middle	Mutidisciplinary	V	3
19	Jeon (2013)	Master's thesis	Elementary	Mutidisciplinary	IV	12
20	Jo (2013)	Master's thesis	Elementary	Mutidisciplinary	I	6
21	Kang (2013)	Master's thesis	Elementary	Mutidisciplinary	III	16
22	Kang et al. (2013)	Journal	Elementary	Mutidisciplinary	I	6
23	Kee et al. (2014)	Journal	High	Mutidisciplinary	III	8
24	Keum & Baek (2013)	Journal	Elementary	Mutidisciplinary	III	10
25	Kim (2012a)	Master's thesis	High	Interdisciplinary	I	8
26	Kim & Hong (2014a)	Journal	Elementary	Interdisciplinary	III	11
27	Kim & Hong (2014b)	Journal	Elementary	Mutidisciplinary	III	9
28	Kim (2013a)	Master's thesis	Elementary	Mutidisciplinary	I	18
29	Kim & Choi (2012)	Journal	Elementary	Interdisciplinary	IV	12
30	Kim & Choi (2013a)	Journal	Elementary	Interdisciplinary	I	6
31	Kim et al. (2013)	Journal	Middle	Mutidisciplinary	III	50
32	Kim (2014)	Master's thesis	Elementary	Mutidisciplinary	IV	18
33	Kim (2012b)	Doctoral thesis	Elementary	Mutidisciplinary	III	7
34	Kim (2013b)	Master's thesis	High	Interdisciplinary	III	4
35	Kim (2013c)	Master's thesis	Middle	Mutidisciplinary	IV	5
36	Kim (2012c)	Master's thesis	High	Interdisciplinary	III	16
37	Kim & Choi (2013b)	Journal	Elementary	Mutidisciplinary	I	16
38	Kim (2013d)	Master's thesis	Middle	Mutidisciplinary	I	18
39	Kim (2013e)	Master's thesis	Elementary	Interdisciplinary	IV	18
40	Kim & Kim (2014)	Journal	Elementary	Interdisciplinary	I	12
41	Kim (2013f)	Master's thesis	Elementary	Mutidisciplinary	III	5
42	Kim (2013g)	Master's thesis	Elementary	Mutidisciplinary	III	20
43	Kim (2013h)	Master's thesis	Middle	Mutidisciplinary	I	6
44	Ko (2014a)	Master's thesis	Middle	Mutidisciplinary	III	13
45	Ko (2014b)	Master's thesis	Elementary	Mutidisciplinary	I	12
46	Kwon (2012)	Master's thesis	Elementary	Mutidisciplinary	III	12
47	Kwon (2014)	Master's thesis	Elementary	Mutidisciplinary	IV	13
48	Lee & Park (2014)	Journal	High	Mutidisciplinary	III	14
49	Lee & Choi (2013)	Journal	Middle	Mutidisciplinary	I	13
50	Lee (2013a)	Master's thesis	High	Mutidisciplinary	I	5
51	Lee (2013b)	Master's thesis	Elementary	Mutidisciplinary	I	12
52	Lee (2013c)	Doctoral thesis	Elementary	Mutidisciplinary	I	10
53	Lee et al. (2013a)	Journal	Middle	Interdisciplinary	V	13
54	Lee (2013d)	Master's thesis	Middle	Mutidisciplinary	I	10

(Continued on next page)

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Table 2. Continued

No.	Authors (year)	Publication type	Subject school type	Integration type	Instruction type	Application period (mo)
55	Lee (2014a)	Master's thesis	Middle	Mutidisciplinary	III	4
56	Lee (2014b)	Master's thesis	High	Interdisciplinary	III	7
57	Lee (2014c)	Master's thesis	Elementary	Mutidisciplinary	I	4
58	Lee (2014d)	Master's thesis	High	Interdisciplinary	I	6
59	Lee (2013e)	Master's thesis	High	Interdisciplinary	III	6
60	Lee (2014e)	Master's thesis	High	Interdisciplinary	III	6
61	Lee et al. (2013b)	Journal	Elementary	Mutidisciplinary	IV	10
62	Lee & Lee (2013)	Journal	Elementary	Mutidisciplinary	I	11
63	Lee & Cho (2012)	Journal	Elementary	Interdisciplinary	III	8
64	Lee & Lee (2014)	Journal	Middle	Mutidisciplinary	I	18
65	Lim (2014)	Master's thesis	High	Mutidisciplinary	III	10
66	Lim & Lee (2014)	Journal	Elementary	Interdisciplinary	I	12
67	Park (2013a)	Master's thesis	High	Mutidisciplinary	I	13
68	Park & Shin (2012)	Journal	Elementary	Mutidisciplinary	II	11
69	Park (2014a)	Master's thesis	Middle	Mutidisciplinary	IV	12
70	Park (2014b)	Master's thesis	High	Mutidisciplinary	III	1
71	Park (2012)	Master's thesis	Elementary	Mutidisciplinary	II	12
72	Park (2013b)	Journal	Elementary	Mutidisciplinary	I	10
73	Park (2014c)	Master's thesis	Elementary	Mutidisciplinary	II	20
74	Ryu (2012)	Master's thesis	Elementary	Interdisciplinary	IV	12
75	Seo (2012)	Master's thesis	Middle	Mutidisciplinary	III	18
76	Seo (2013)	Master's thesis	Elementary	Interdisciplinary	IV	12
77	Song & Lee (2011)	Journal	Elementary	Mutidisciplinary	II	12
78	Sung & Na (2012)	Journal	High	Interdisciplinary	I	24
79	Tae & Park (2013)	Journal	Elementary	Mutidisciplinary	III	10
80	Yang & Hong (2014)	Journal	Elementary	Interdisciplinary	I	9
81	Yim (2014)	Master's thesis	High	Mutidisciplinary	I	11
82	Yoon (2013)	Master's thesis	Middle	Mutidisciplinary	I	8
83	Yu (2013)	Master's thesis	Elementary	Mutidisciplinary	IV	15

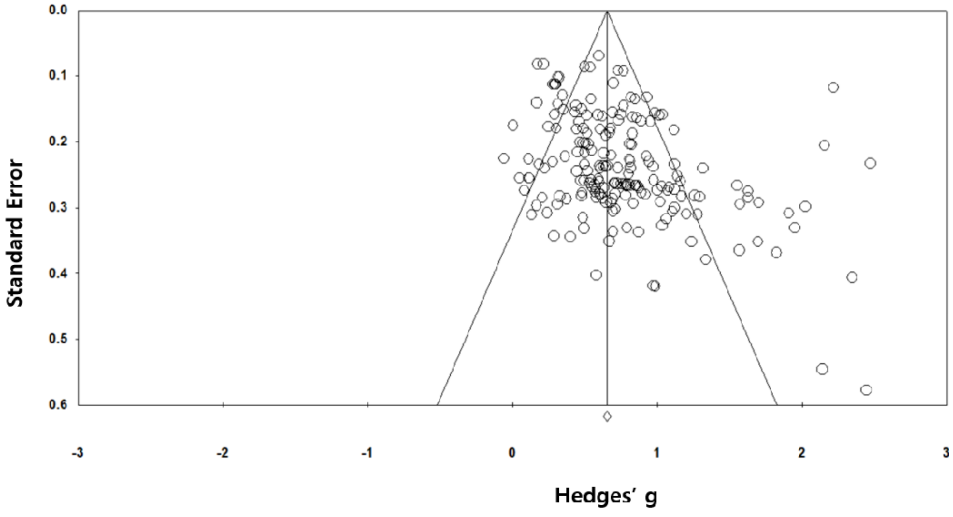


Fig. 2. Analysis of publication bias by funnel plot.

ports the research result that mostly fusion and multidisciplinary approaches are used in the curricula of integrative education leader schools (Lee & Kim, 2013). Therefore, it is necessary to select appropriate integration subjects based on a thorough examination of curricula and to develop and apply STEAM programs with various integration types instead of ineffectively linking different subjects or integrating subjects by combining fragmented knowledge.

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2) Research trends according to school levels of STEAM education programs

Table 5 presents the research trends according to the school levels of STEAM education programs. Of all the STEAM programs, the studies applied to elementary schools accounted for 59.0% (49 studies), those applied to middle schools accounted for 21.7% (18 studies), and those applied to high schools accounted for 19.3% (16 studies), which shows a concentration of STEAM programs in elementary schools. More effort must be made to apply STEAM education to middle and high schools.

Table 3. Number of the selected STEAM education researches

Year	Number of research
2010	1
2011	2
2012	13
2013	37
2014	30
Total	83

STEAM = science, technology, engineering, arts, and mathematics.

2. Publication bias

Five methods are recommended to ensure no bias in collecting subjects in meta-analysis. To verify no publication bias, using two or more methods is recommended (Oh, 2002). If there was no bias in collecting the analysis subjects, the effect size presented in the dots will be horizontally symmetrical in the funnel plot that shows the relationship between the sample size and effect size. In this study, the publication bias of individual effects was verified visually using a funnel plot. As shown in Fig. 2, some of the research results were distributed asymmetrically on the bottom right, suggesting the existence of publication bias.

It is also possible to verify publication bias using Egger's test, which is the most commonly used method for the statistical analysis of symmetry in a funnel plot (Egger et al., 1997). According to Egger's regression analysis, the regression intercept was 1.75, the standard error was 0.36, and the initial value of the regression equation was significant at 0.05 ($p < 0.05$). Using these two methods, publication bias was found in this meta-analysis. Therefore, to examine the extent to which

Table 4. Trend of STEAM education research by integration type

Year	Integration type			Total
	Multi-disciplinary	Inter-disciplinary	Trans-disciplinary	
2010	0	1	0	1
2011	2	0	0	2
2012	7	6	0	13
2013	30	7	0	37
2014	20	10	0	30
Total	59	24	0	83
%	71.1	28.9	0	100

STEAM = science, technology, engineering, arts, and mathematics.

Table 5. Trend of STEAM education research by subject school type

Year	School type			Total
	Elementary school	Middle school	High school	
2010	1	0	0	1
2011	1	1	0	2
2012	8	2	3	13
2013	23	10	4	37
2014	16	5	9	30
Total	49	18	16	83
%	59.0	21.7	19.3	100

STEAM = science, technology, engineering, arts, and mathematics.

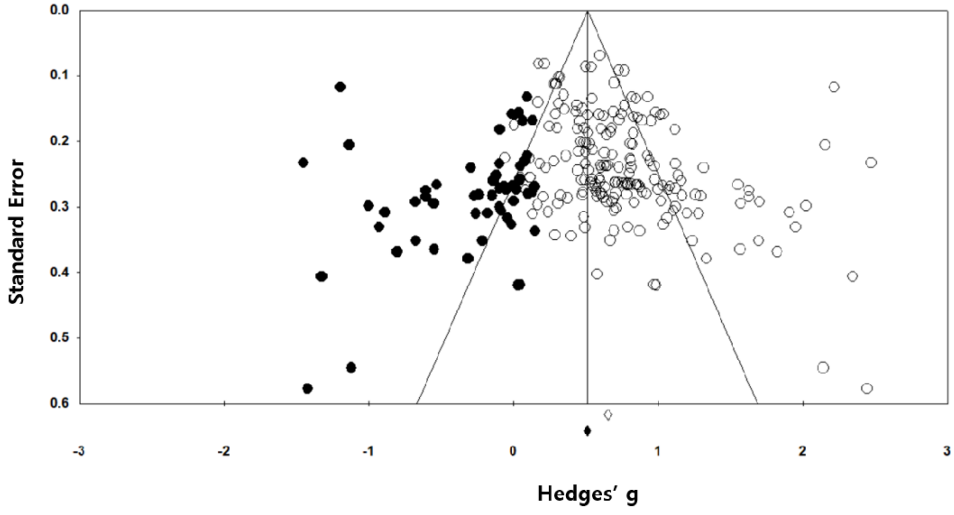


Fig. 3. Funnel plot through trim-and-fill method.

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the bias affected the results of this study, the trim and fill method developed by Duval and Tweedie (2000) was used.

As shown in Fig. 3, using the trim-and-fill method to estimate the effect sizes that were not reported due to the publication bias and filling them with black dots to correct the asymmetry, the effect size slightly changed from the white rhombus to the black rhombus. In the end, the overall publication bias analysis suggests that publication bias existed in the papers used as subjects in this study, but the effect was insignificant.

3. Analysis of the overall average effect size

The meta-analysis was conducted on the effects of STEAM programs in 83 studies, and, for the sub-group analysis, 188 effect sizes were used. The effect sizes extracted from the previous research were heterogeneous ($Q = 851.636$, $p < 0.05$). Therefore, in this study, the random effect model was used to measure the overall effect size. Table 6 shows the analysis of the overall effect size of STEAM programs.

In the random model, the overall effect size was 0.751, and the 95% confidence interval of the effect size was between 0.687 and 0.814. According to the standard for effect size interpretation proposed by Cohen (1988), this is larger than the medium size effect. In addition, it was larger than 0.40, the overall effect size found in the meta-analysis on the effects of the Science and Technology in Society (STS) instructional model by Jung et al. (2008), larger than 0.61, the overall effect size found in the meta-analysis on the effects of science experiment classes conducted by Yi (2007) and larger than 0.50, the overall effect size found in the meta-analysis on the effects of inquiry-based science teaching conducted by Furtak et al. (2012). On the other hand, it was smaller than 1.48, the overall effect size found in the meta-analysis on the effects of integrated education research by Kim et al. (2015).

Kang (2019) analyzed 6 meta-analyses regarding the effects of STEAM education in South Korea from 2012 till 2018, and showed medium to high effects on student learning. Those studies also examined a number of variables that could moderate the effect, but most of those variables including sample size, number of STEAM class periods and lesson product types and others did not seemed to significantly moderate the effect size.

4. Sub-group analysis

1) Effect size according to publication type

Table 7 presents the analysis related to the difference in the effects of STEAM programs according to publication type and its statistical significance. The effect size according to publication type was largest in master's theses (0.763), followed by journal articles (0.737), and then doctoral dissertations (0.719). While theses published in journal articles were coded as 'journal articles', ones that were not published in academic journals were coded as 'master's'. According to the standard for effect size interpretation proposed by Cohen (1988), master's theses, journal articles, and doctoral dissertations had a larger effect size than the medium size.

2) Effect size according to school level

Table 8 presents the analysis related to the difference in the effects of STEAM programs according to school level and its statistical significance. The effect size according to school level was largest in elementary schools (0.793), followed by middle schools (0.732), and then high schools (0.651). According to the standard for effect size interpretation proposed by Cohen (1988), elementary schools, middle schools, and high schools all had a larger effect size than the medium size.

Table 6. Overall effect size for STEAM education programs

Model	K[a]	Q[b]	*p*-value[c]	ES	95% CI	SE
Fixed	188	851.636	<0.001	0.660	0.632–0.688	0.014
Random	188			0.751	0.687–0.814	0.032

STEAM = science, technology, engineering, arts, and mathematics.
[a]Number of effect size. [b]Statistical test of homogeneity. [c]Significance level of the homogeneity test.

Table 7. Effect size by publication type

Publication type	K[a]	Q[b]	*p*-value[c]	ES	95% CI	SE
Master's	105	494.102	<0.001	0.763	0.677–0.850	0.044
Doctoral	7	5.161	0.523	0.719	0.489–0.949	0.118
Journal	76	346.499	<0.001	0.737	0.638–0.836	0.050

[a]Number of effect size. [b]Statistical test of homogeneity. [c]Significance level of the homogeneity test.

Table 8. Effect size by subject school type

Subject school	K[a]	Q[b]	*p*-value[c]	ES	95% CI	SE
Elementary	107	366.898	<0.001	0.793	0.695–0.790	0.046
Middle	43	375.075	<0.001	0.732	0.588–0.877	0.074
High	38	91.131	<0.001	0.651	0.559–0.743	0.047

[a]Number of effect size. [b]Statistical test of homogeneity. [c]Significance level of the homogeneity test.

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3) Effect size according to student characteristics

Table 9 presents the analysis related to the difference in the effects of STEAM programs according to student characteristics and its statistical significance. The effect size according to student characteristics was larger in gifted students (0.997) than in general students (0.712). According to the standard for effect size interpretation proposed by Cohen (1988), gifted students and general students had an effect size larger than the medium size, which suggests applying STEAM education programs to gifted students is highly effective. This result was similar to one of Kim et al. (2015) that the integrated education programs proved to be more effective on gifted students compared to regular students.

4) Effect size according to integration type

Table 10 presents the analysis related to the difference in the effects of STEAM programs according to integration type and its statistical significance. The effect size according to integration type was larger in multidisciplinary integration (0.765) than in interdisciplinary integration (0.731). According to the standard for effect size interpretation proposed by Cohen (1988), both integration types had an effect size larger than the medium size.

5) Effect size according to class type

Table 11 presents the analysis related to the difference in the effects of STEAM programs according to class type and its statistical significance. The effect size according to class type was largest in Type IV (0.986), followed by Type II (0.795), Type III (0.724), Type V (0.691), and Type I (0.686). According to the standard for effect size interpretation proposed by Cohen (1988), Type VI had a large effect size, and Types II, III, V, and I had effect sizes larger than the medium size. This no study supports the finding that applying STEAM education programs to gifted students is highly effective.

In addition, classes in which different subjects are integrated (Type II) or those in which the curricula are reorganized based on a central theme using other times than regular classes (Type III, V) had a large effect size. In fact, the effect sizes are larger than classes in which elements from science, technology, engineering, art, and mathematics are integrated into a central subject without reorganizing the curricula (Type I). This result was similar to one of Kim et al. (2015) that the integrated education programs implemented in after school hours were more effective than in regular school hours.

6) Effect size according to dependent variables

The difference in the effects of STEAM programs according to dependent variables and its statistical significance were analyzed. Because various test tools were used to verify the effects of STEAM programs, only the results obtained using tools that were used five times or more in the subjects' studies were presented in Table 12.

The effect size according to dependent variables was largest in creativity (1.004), followed by science inquiry ability (0.863), attitude toward science (0.819), creative problem-solving skills (0.708), academic achievement (0.636), and attitude toward mathematics (0.612). The effects of the sub-domains of the attitude toward science were largest in scientific attitude (0.932), awareness (0.850), interest (0.746), and self-efficacy (0.653). According to the standard for effect size interpretation proposed by Cohen (1988), creativity, science inquiry ability, and attitude toward science had large effect sizes, and creative problem-solving skills, academic achievement, and attitude toward mathematics had effects larger than the medium size. The STEAM education programs in this study had larger effect sizes than the effect sizes of integrative science education suggested in the meta-analysis conducted by Lee et al. (2012) (scientific knowledge = 0.65, science inquiry ability = 0.83, attitude toward science = 0.63). In addition, they were larger than the ef-

Table 9. Effect size by subject student type

Subject student	K[a]	Q[b]	*p*-value[c]	ES	95% CI	SE
General	159	752.277	<0.001	0.712	0.644–0.780	0.035
Gifted	29	64.254	<0.001	0.977	0.831–1.123	0.075

[a]Number of effect size. [b]Statistical test of homogeneity. [c]Significance level of the homogeneity test.

Table 10. Effect size by integration type

Integration type	K[a]	Q[b]	*p*-value[c]	ES	95% CI	SE
Multidisciplinary	124	666.886	<0.001	0.660	0.626–0.694	0.017
Interdisciplinary	64	180.138	<0.001	0.633	0.586–0.680	0.024

[a]Number of effect size. [b]Statistical test of homogeneity. [c]Significance level of the homogeneity test.

Table 11. Effect size by class type

Class type	K[a]	Q[b]	*p*-value[c]	ES	95% CI	SE
I	78	466.102	<0.001	0.686	0.577–0.795	0.056
II	14	9.381	0.744	0.795	0.655–0.936	0.072
III	60	247.850	<0.001	0.724	0.621–0.826	0.052
IV	28	63.871	<0.001	0.986	0.836–1.135	0.076
V	8	22.715	<0.001	0.691	0.471–0.910	0.112

[a]Number of effect size. [b]Statistical test of homogeneity. [c]Significance level of the homogeneity test.

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fect sizes of the STS class model in science education suggested in the meta-analysis conducted by Jung et al. (2008) (science inquiry ability = 0.41, attitude toward science = 0.42, academic achievement = 0.33). They were also larger than the effects of science experiment classes in the meta-analysis conducted by Yi (2007) (science inquiry ability = 0.70, attitude toward science = 0.50, scientific knowledge = 0.56) and the effects of cooperation learning in science classes meta-analyzed by Seo (2013) (science inquiry ability = 0.40, attitude toward science = 0.28, scientific knowledge = 0.36).

7) Effect size according to publication year

Fig. 4 presents the results of the meta-regression analysis on the relationship between the effect size of STEAM programs and the publication year, which is a continuous variable. The suitability of the regression model was Q = 0.51 (df = 1, $p > 0.05$); therefore, it was statistically insignificant, and the gradient coefficient was 0.028 (z = 0.71, $p > 0.05$), which is also insignificant.

Table 12. Effect size by dependent variable

Dependent variable	K[a]	Q[b]	*p*-value[c]	ES	95% CI	SE
Creativity	22	69.640	<0.001	1.004	0.813–1.195	0.097
Science process skills	8	22.331	0.002	0.863	0.542–1.185	0.164
Ats	16	179.899	<0.001	0.819	0.503–1.136	0.161
Scientific attitude	12	76.149	<0.001	0.932	0.598–1.266	0.170
Recognition	6	40.521	<0.001	0.850	0.410–1.291	0.225
Interest	17	58.726	<0.001	0.746	0.574–0.917	0.088
Self confidence	9	25.447	0.001	0.653	0.440–0.866	0.109
Creative problem solving	5	0.993	0.911	0.708	0.496–0.919	0.108
Academic achievement	23	97.248	<0.001	0.636	0.411–0.860	0.114
Attitude toward mathematics	6	1.809	0.875	0.612	0.417–0.806	0.099

Ats = attitude toward science.
[a]Number of effect size. [b]Statistical test of homogeneity. [c]Significance level of the homogeneity test.

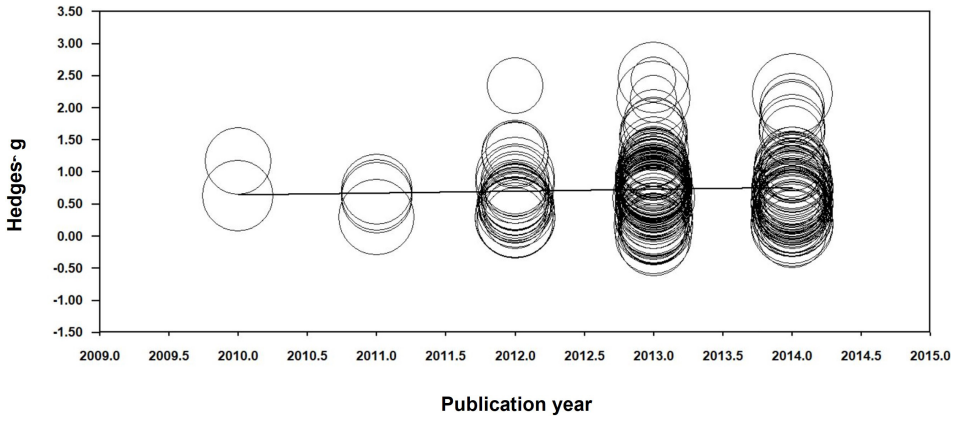


Fig. 4. Meta regression result by publication year.

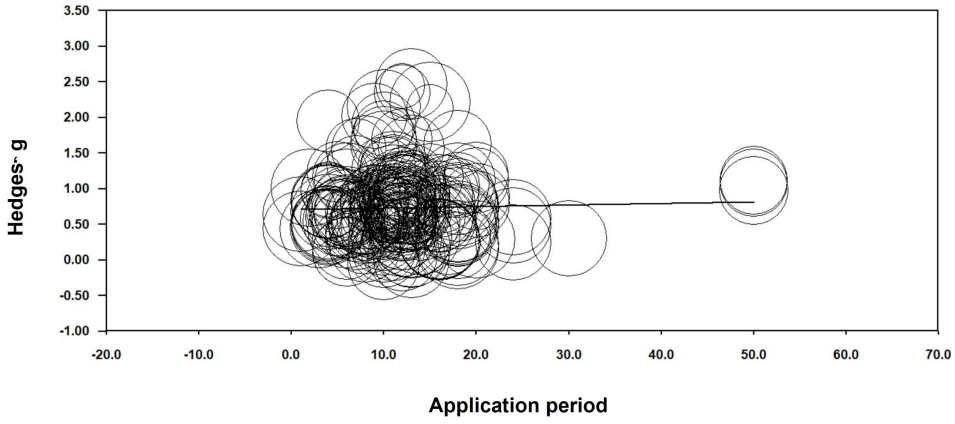


Fig. 5. Meta regression result by application period.

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8) Effect size according to application period

Fig. 5 presents the results of the meta-regression analysis on the relationship between the effect size of STEAM programs and the period, which is a continuous variable. The suitability of the regression model was Q = 0.18 (df = 1, $p > 0.05$); therefore, it was statistically insignificant, and the gradient coefficient was 0.002 (z = 0.42, $p > 0.05$), which is also insignificant.

CONCLUSION AND SUGGESTIONS

In this study, the overall trends of research on STEAM programs published in South Korea between 2010 and 2014 were investigated, and a meta-analysis on the effects of STEAM education programs was conducted based on the relevant studies. The detailed discussion of the results of this study is as follows.

First, the integration of STEAM programs concentrated on the multidisciplinary type. Interdisciplinary-type programs were rare, and the effect size of these programs was smaller than that of multidisciplinary-type programs. Since multidisciplinary integration helps students to learn each theme more explicitly, learning effect of this type appears to be larger. Therefore, when designing STEAM education programs, it is necessary to apply various integration types by rigorously reviewing the curricula and selecting suitable integration themes.

Second, the overall average effect size of STEAM education programs was 0.751, which is larger than the medium size and larger than the effects of applying an STS instructional model in science education and science experiment classes. Our result is comparable to some of recent meta-analysis studies in which STEAM education presented a medium effect size (Rho & Yoo, 2016; Kang et al., 2018; Shin, 2018). Since STEAM education in South Korea showed a distinguished educational effect, it could be exploited more.

Third, the effect size according to the dependent variables was largest in creativity followed by science inquiry ability, attitude toward science, creative problem-solving skills, academic achievement, and attitude toward mathematics, in that order. In addition, when compared with other meta-analyses, classes using STEAM education programs had larger effects in science inquiry ability, attitude toward science, and science-related academic achievement than in science integration education, STS instructional models, science experiment classes, and cooperation learning in science classes. It was also determined that larger effect size appears to reside in the area of affective domain. Because STEAM education presented instructional effect not only on students' cognitive domain but also on their affective domain, it may help to raise the creative convergence talent. However, the effects of STEAM programs were mostly investigated concerning creativity, science inquiry ability, attitude toward science, creative problem-solving skills, academic achievement, and attitude toward mathematics, while it was not examined whether STEAM education helped students improve their abilities or prepare for the future. Such limitation may have caused by the lack of the evaluation tools for the appropriate competencies, analysis of effect based on subject education, difficulties in experimental design, and others. Therefore, it would be necessary to develop various STEAM education programs to enhance key competencies for the future society and to apply them in the school.

Fourth, STEAM programs were mostly frequently applied to and had the largest effect size in elementary schools. It is necessary to develop effective STEAM programs that can be used in middle and high schools to provide opportunities for students to solve practical programs and combine a high level of knowledge in different disciplines.

Fifth, the effect size according to student characteristics was larger in gifted students than in general students, and the effect size according to class type was larger in classes in which the curricula were reorganized for STEAM education than in the single-subject class type. Therefore, it is necessary to diversify program contents and develop STEAM programs for a single subject that can be provided as part of the regular curricula so that students in general can benefit from STEAM education.

Based on the results of this study, the implications for STEAM education are summarized as follows:

First, since we have found STEAM education was useful to enhance educational effects through this meta-analysis, STEAM education needs to be actively encouraged in K-12 education. It has been more than ten years since STEAM education was officially launched in South Korea. Many studies suggested various results related to the effects of STEAM education. In this study, a meta-analysis verified the effects of various STEAM programs on creativity, science inquiry ability, attitude toward science, academic achievement, and attitude toward mathematics. As the positive effects of STEAM education have been clearly demonstrated, teachers should not give up on STEAM education due to a lack of competence, relevant programs, or time for researching teaching materials. And, they do not spare any costs for the personal and material support to carry out STEAM education in schools.

Second, we need to expand STEAM education programs to out-of-school activities in addition to the reg-

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ular subject lesson. Our result presented that STEAM education has also excellent educational effects in the gifted education, and out-of-school activities. If learners want, they could experience varied STEAM education programs as out-of-school activities. We could enhance its educational effects by practicing STEAM education coupled with broad variety of materials in the local societies such as library, museum and art museum.

Third, we need to build the environment for the teachers to show their competence for the design of STEAM education. Professional development opportunities create learning structures that help teachers to easily explore unknown complex concepts, be innovative in their own instruction (Baker-Doyle & Yoon, 2011). So, it is necessary to propose a method for designing effective STEAM classes. In addition, it is important to increase the autonomy of unit schools in operating curricula and to activate STEAM research groups composed of teachers of different disciplines within the school, so that teachers planning STEAM classes do not have difficulties with, for instance, conducting STEAM classes linked with other subjects and classes outside of regular class times.

Based on the results and conclusions so far, this study would like to suggest the following for further study. First, we need to find out structural relationship in the individual variables further. If we know which instructional type has the larger effect to specific learner, it will provide implications regarding the customized educational program for the specific learner. Second, while this study also presented an effect size based on integration type, current studies so far did not contain the integration type. Further study could be needed since teaching-learning methods and their instructional effect will be different according to the integration type. Third, it is necessary to develop a STEAM instructional model that helps students develop competence for the future. As one of the roles of education is to foster future citizens and workers who can effectively respond to challenges in the future, STEAM programs need to encourage an integrative approach to science and other disciplines to help students solve practical problems in the future

Availability of data and material

Raw data are available upon request from the corresponding author.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Hye-Mi Jeong was involved in conceptualizing the study, determining the methodology, reviewing literature and resources, analyzing data and writing original draft and manuscript. Hyuksoo Kwon was involved in determining the methodology, collecting the data, conducting the analysis of the data and reviewing draft and editing. Sung-Ha Kim supervised the project and was involved in conceptualizing the study, overseeing the analysis of the data, revising the manuscript and responding to reviewers. All authors read and approved the final manuscript.

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