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Meta-Analytic and Meta-Thematic Analysis of STEM Education

Veli Batdı[1], Tarık Talan[2], Çetin Semerci[3]
[1]Kilis 7 Aralik University
[2]Gaziantep Islam, Science and Technology University
[3]Bartin University

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Abstract

The purpose of this study was to examine STEM (Science, Technology, Engineering, Mathematics) education in meta-analytical and meta-thematic terms and to determine its impact on academic achievement and different variables. In this context, studies carried out on STEM between 2002-2019 were chosen. Data from 26 studies were included in the study and analyses were made using these data. CMA and MetaWin softwares were used in analyzing the data and the impact of STEM on academic achievement was found to be significant and positive at medium level (ES=0.655). In the second phase of the study, which was the meta-thematic phase, the contribution of STEM on cognitive and affective areas as well as on individual competences, personal development, skill development and the difficulties encountered during the implementation were given. The results of meta-analytical and meta-thematic findings indicated that STEM had a positive impact on academic achievement and development of different skills.

Introduction

The increasing economic, social, scientific and technological developments in recent years increased the need for collaborative, reasonable, creative, questioning, and innovative individuals who can work in harmony in a group. The way to meet this need is, without doubt, through education. It is not possible to equip students with the mentioned skills through traditional teacher-centered education (Roberts, 2012). In order to facilitate the productivity of the individuals, in addition to creating new and effective approaches to meet the demanded circumstance, it is necessary to bring together knowledge from different areas, prepare projects and carry out these projects by turning them into production. At this point, STEM (Science, Technology, Engineering, Mathematics), as an interdisciplinary approach, stands out as an increasingly important approach which develops lifelong learning skill (Yıldırım & Altun, 2015). Therefore, STEM, which is based on integration of Science, Engineering, Mathematics disciplines with technology in educating the human profile required in the 21stcentury, is the key to solving the problems of today and the future (Brophy et al., 2008).

This education approach, which has been at the center of the developments in education in the recent years, is a student-centered approach with an emphasis on collaborative learning and it associates and combines Science, Mathematics, Technology and Engineering disciplines and the skills of these disciplines (Herschbach, 2011; Meng, Idris & Kwan, 2014). In addition, STEM can be defined as an education approach in which an integrated education involving the knowledge and skills of four disciplines and in which equipping students with cooperation, systematic thinking, effective communication, research and questioning, creative thinking and problem solving skills, are aimed at (Bybee, 2010; Dugger, 2010; Rogers & Porstmore, 2004). There are different definitions and approaches to STEM in the literature. However, the common ground of these definitions and approaches is that STEM is an interdisciplinary approach and is used in real-life context (Srikoom, Faikhamta & Hanuscin, 2018).

STEM, which necessitates the use of technology in the classes and which offers the development of such 21st century skills as questioning, critical thinking, imagining, entrepreneurship and discovering (Bybee, 2010) is an education system preferred in many countries in the world today. This system, which involves more than one discipline, aims at enabling students to have an interdisciplinary viewpoint against problems, equpping them with knowledge and skills through a holistic educational approach and implementing the knowledge in real life (Şahin, Ayar & Adıgüzel, 2014). In addition to developing high-order thinking skills, STEM aims at putting theoretical knowledge into practice and turning it into product and invention and emphasizes the improvement of innovative and productive skills of the students (Morrison, 2006). Therefore, it is possible to say that the purpose of STEM education is to remove the distinction among disciplines, to create a single discipline and thus, to educate a generation who question, research, produce and make inventions throughout the whole education process starting from pre-school until higher education (Murat, 2018).

Although the introduction of STEM dates back to 1990s, it was in 2001 when the term was produced as an educational term by Judith A. Ramaley, an administrator of 'The National Science Foundation (NSF)', and since then, it has become widespread rapidly (NSF, 2001; Yıldırım & Selvi, 2015). Increasing importance of STEM education is due to the interdisciplinary interaction it incorporates. Therefore, it is possible to say that STEM education enables students to develop in many aspects. Students educated with STEM are problem solvers, innovative people who have self-esteem, who make logical decisions, have high-order and critical thinking skills, and who are science and technology literate (Morrison, 2006; National Research Council, 2009). In addition, evidence suggests that students' planning, critical thinking, analysis and synthesis skills develop through STEM education and they can implement what they learn in problems they encounter (Morrison, 2006). On the contrary, students who lack STEM skills have difficulty in orienting towards occupations related to Science and Engineering or fields that require Mathematics, Science and Technology literacy (Merrill & Daugherty, 2010).Therefore, with STEM education, this distinction between different courses is aimed to be removed and a generation who are capable of making projects, researching and producing, making discoveries and questioning from pre-school until tertiary education will be educated.

Moreover, there are studies indicating that STEM education, which is based on constructivist theory and student-centered education, creates a convenient learning environment (Lantz, 2009; Şahin, Ayar & Adıgüzel, 2014), enables students to develop a positive attitude towards Science classes (Tseng et al., 2013) and increases academic achievement (Han, 2013; Yıldırım & Altun, 2015). Apart from these studies, it is also indicated in the relevant literature that STEM education contributes to developing critical thinking (Şahin, Ayar & Adıgüzel, 2014; Wosu, 2013), experiential learning and problem solving (Pekbay, 2017; Saleh, 2016; Wosu, 2013) and improving self-esteem (Morrison, 2006). In this context, it is possible for students who are offered STEM education at an early age to view things from different points of view, to have problem solving skills and make innovations (Özmen, 2018). Therefore, this study was carried out to examine STEM education, which has a holistic impact on student development and equips students with skills to view things from different point, and share the results.

The Purpose of the Study

The education needed today has changed and the development of individuals' knowledge and skills has become more important. The skills that the individuals of today have are defined as effective communication, critical and creative thinking, expressing oneself, algorithmic thinking, problem solving and offering original ideas (Turner, 2013). The development of these knowledge and skills will not only increase the self-esteem, productivity and responsibility skills and the awareness level of the individuals but also improve their communication competences. The contribution of STEM education, which has gained importance in recent years, in creating this awareness is significant (Bybee, 2010). In the literature review, it can be clearly seen that STEM has been mainly used in many researches especially in these days (Ikuma et al, 2019; Mestre, Cheville & Herman, 2018). STEM, which has been mentioned frequently lately, is highly important for students to acquire the adequate knowledge on time. In this respect, the skills students acquire during their education guarantee contributions to themselves in their profession and to the economy of the country. STEM education enables students to handle existing problems with an interdisciplinary approach and thus, enables them to access the knowledge and skills expected. Therefore, this education approach is highly important in terms of equipping students with 21st century skills, enabling them to specialize in different fields and creating an environment where future generations join the workforce in these fields. At this point, there is a need for inclusive and reliable meta-studies for interpreting the accumulation of knowledge on STEM and thus, opening ways for new studies. By using meta-analysis and meta-thematic methods offering a holistic and inclusive viewpoint, this study aims to examine the efficiency of STEM approach in educational environments. In this respect, it is believed that this study will contribute to educational research and will be a guide for educators who want to use STEM approach. Considering this main objective, this study was guided by the following research questions:

1. What is the effect size of STEM on academic achievement?
2. What is the effect size of STEM on academic achievement in terms of school stages?
3. What is the effect size of STEM on academic achievement in terms of implementation periods?
4. What is the efficiency of STEM within the scope of meta-thematic analysis based on document analysis?

Method

The purpose of this study was to examine independent studies carried out on the use of STEM approach in education and to re-interpret these studies. To this end, a methodological process involving the use of qualitative and quantitative methods was utilized.

Research Type and Design

In the quantitative dimension of the study, meta-analysis method was used to determine if STEM approach was efficient on academic achievement. Meta-analysis, as a literature review method, involves combining the results of independent studies carried out on a certain topic using quantitative approach and analyzing the research findings statistically (Cohen, Manion, & Morrison, 2002; Littel, Corcoran & Pillai, 2008). The most important feature of meta-analysis which distinguishes it from other literature review methods is that it is based on statistical techniques and numeric data (Özcan, 2007). In addition, in order to determine the effect size of some studies which are believed to have an effect on studies carried out on STEM, moderator analysis of some variables was conducted. The moderators of this study were proposed as; implementation period, the discipline/course in which STEM was implemented and sample size.

Moreover, in order to make more in-depth review on the topic, offer more comprehensive information, and bring rich data to the study qualitative dimension (meta-thematic analysis) was included (Batdı, 2017a). The concept of meta-thematic analysis was coined by Batdı, (2017b). The purpose is to bring together the participant opinions in qualitative studies carried out on the concept. From this point of view, it is a method which involves the process of revising the themes composed of ideas. During the meta-thematic analysis process, the data collected through document review were interpreted. Document review is the process of examining the resources and document related to the research topic and making the necessary arrangements to synthesize the possible opinions to arise (Karasar, 2007).

Data Collection

In the process of collecting the data, first of all, the databases and search criteria were determined. For the current study, the ProQuest Dissertation & Thesis Global, Higher Education Council's Thesis Center, Web of Science, ERIC (EBSCO), Wiley Online Library Full Collection, Scopus (A&I), Taylor & Francis Online, Science Direct and Springer LINK databases were used. The key words used in search were "STEM" and "FeTeMM". The languages were chosen as Turkish and English. The timespan for the studies were restricted to 2002-2019.

Studies which did not comply with inclusion criteria and did not have the necessary statistical data were not included in the analysis. Studies conducted in different fields and carried out with different sample groups were considered individual studies. That is to say, certain studies included such data as it belonged to two different studies. Thus, these studies were considered as two separate studies. In order to get standard effect size, whether the studies had an experimental-control group was taken into account and those studies having experimental and control groups were included in meta-analysis. Experimental group represents the group using STEM approach while control group represents traditional environments. Information about the collected data on the studies are given in Figure 1 in line with PRISMA flow diagram (Moher et al., 2009).

It is seen in Figure 1 that as a result of database searching made to identify the impact of STEM on academic achievement, 751 studies were found. Of these studies, 28 were taken out because they were copies and 342 were taken out after their abstracts were read and it was seen that they were irrelevant. The remaining 381 studies were examined considering the inclusion criteria and 312 studies were eliminated. Among the remaining 69 studies, 38 studies were again removed because they did not involve sufficient data and another 5 studies were removed because their qualities were low. As a result, 26 studies were included in the meta-analysis.

Coding Method

Before the statistical analysis, based on the purpose of the study, a coding form to compare the features of the included studies was created. The coding form created has two parts. The first part includes information on the author, the publishing year, the discipline/course the study was implemented, school stages, and type of publication; whilst the second part includes data [sample size (N), mean (X), standard deviation (SD)] necessary to calculate the effect size of the studies.

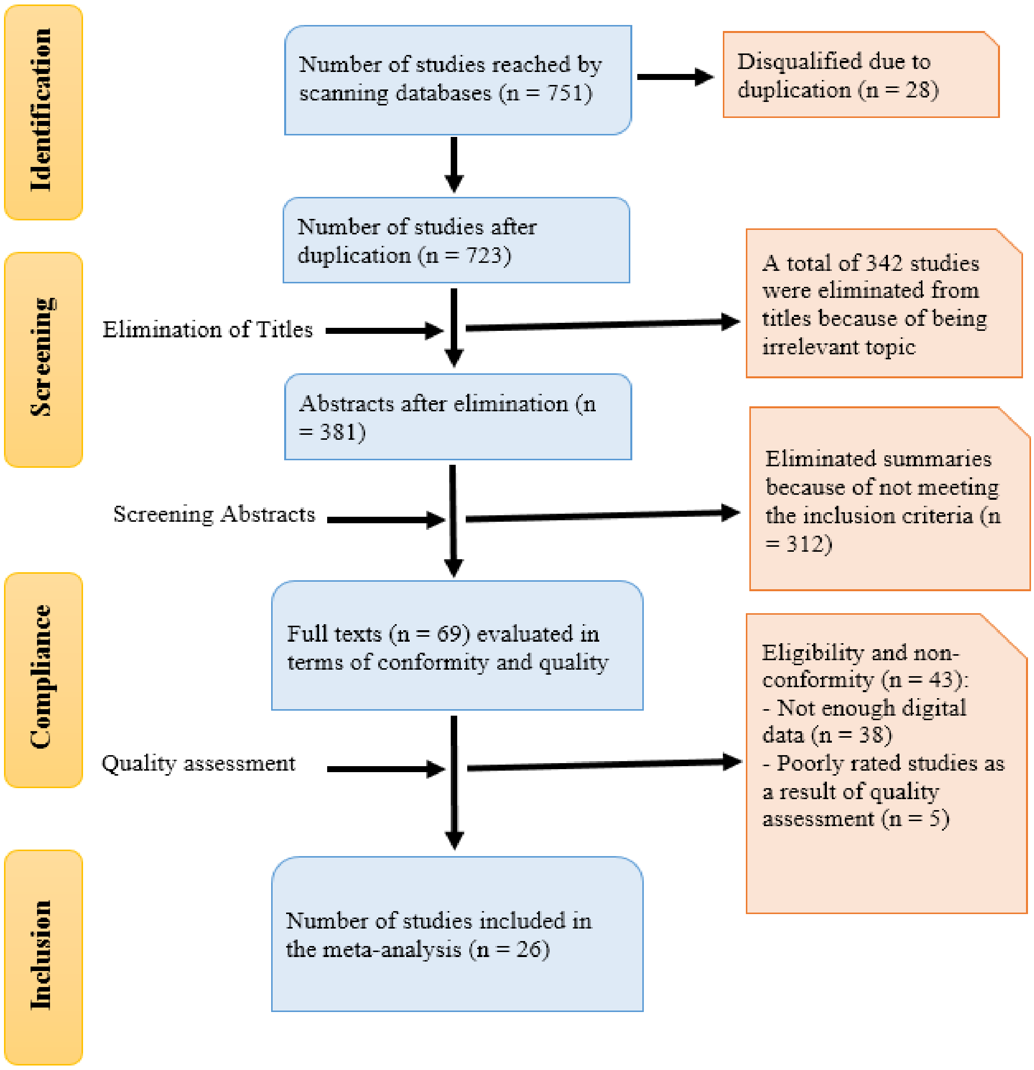

Figure 1. Flow chart for selection of works (flow diagram)

The titles and abstracts of all the studies determined based on inclusion and exclusion criteria were examined and the full text of all the chosen publications were evaluated. To ensure the reliability of the study, the chosen studies were examined in detail by two independent raters and then, a common decision was made for studies on which each rater had different ideas. In this process, reliability between the coders was also calculated.

Data Analysis

In the data collection process, the collected data were transferred to a Microsoft Office Excel file and descriptive analyses were filtered, the frequency and percent of the relevant findings were calculated. CMA and MetaWin programs were used in the analysis of the data and the effect size, test of heterogeneity and publication bias were made through this software. Classification of effect sizes differs. While interpreting the effect sizes in this study, Cohen's (1992) classification was used. Accordingly, if the value calculated is 0.10 - < 0.50, it has a small effect size; if it is 0.30 – < 0.50, it is medium and if it is ≥ 0.50 than it is large. In the study, effect sizes were calculated using random effects model. Furthermore, the direct citations were shown with study code and page number (to set an example: 513968-p.109 means the page 109 from the study coded 513968 or M7-p.378 means citation from the page 378 of the article number 7).

The reliability and validity measurements of the qualitative dimension of the study were carried out. To ensure the consistency in findings of the study, forming a completeness with the consistency and significance of the themes and codes between themselves was aimed to be achieved. In order to ensure the coder reliability, Cohen's Kappa statistics, giving the consistence between the coders, was used (Random effects model (REM) however, values occurring according to fixed effects model (FEM) were included in the findings (Table 1).

The reliability of the study was calculated using the inter-rater reliability level formula [number of agreements / (number of agreements+ disagreements) x 100] (Miles & Huberman, 1994) and was found as 100%. In the qualitative dimension of the study, which enriched the data cluster and expanded the scope of the study, the qualitative studies on STEM (n=7) were analyzed using MAXQDA-11 Program. The data analysis was made according to content analysis. Content analysis, named as an analysis method, is grouping similar data collected within the scope of a study under themes and codes and thus, offering the reader a more understandable product (Yıldırım & Şimşek, 2013). In this study, qualitative findings were found by reorganizing the similar/common themes and codes in other studies on STEM in a certain consistence and order, and these findings were presented in models. Moreover, the expressions from the studies, where the codes and themes were taken, were given in the text while presenting the findings in order to support, justify, and, most importantly, ensure reliability. While making these citations, sentences were not changed and directly presented as they (Yıldırım & Şimşek, 2013). If the compliance values are in the range of .61 and .80, 'a good level of compliance'; if of .81 and 1.00 'very good level of compliance' can be interpreted (Viera & Garrett, 2005). In the present study, the compliance value ranges between .722 and .802 which means 'very good compliance' (Appendix-1).

Results

In this section, the results on STEM practices are interpreted. In the first part, the meta-analysis of the relevant studies is presented. In the second part, results in the context of meta-thematic analysis including the opinions of the participants of studies on STEM are given.

Results on the Effect Size of the Studies on Academic Achievement

When Table 1 is examined, as a result of the analysis made based on random effects model (REM) it is seen that academic achievement in STEM practices is better than traditional teaching methods with standard error 0.067; the upper limit of 95% confidence interval at 0.787 and lower limit at 0.523 and average effect size at 0.655. When the attained effect size is examined, it is accepted as medium effect size based on Cohen's (1992) classification. The result of z-test made to find out statistical significance showed z=9.728. The result reached accordingly showed p=0.000 which means that the analysis is statistically significant. Based on the test of homogeneity, statistical value for Q was calculated as 63.243. $\chi 2$ table shows $\chi 2 = 56.942$ at 95% significance level and 43 degree of freedom. Chi-square distribution with 63.243 Q statistical value and 43 degree of freedom was found to exceed critical value ($\chi 2_{(0.95)} = 56.942$). The average effect sizes of 44 studies included in the meta-analysis based on effect models are shown in Table 1. The impact of STEM practices on academic achievement is in favour of STEM practices with SEM 0.248 and REM 0.655. On the other hand, the homogeneity values in both models were found to exceed critical value. Therefore, the effect size distribution could be considered heterogeneous. It is emphasized that the reason of heterogeneous distribution is because of sampling error.

Table 1. Statistical values according to the effect models related to the academic achievement scores

Model Type	n	Z	p	Q	ES	% 95 Confidence Interval	
						Lower Limit	Upper Limit
SEM	44	12.567	0.000	352.716	0.248	0.210	0.287
REM	44	9.728	0.000	63.243	0.655	0.523	0.787

The Efficiency of STEM Practices Based on the School Stages where STEM Practices were carried out

The total effect sizes of the studies included in meta-analysis was determined based on the school stages. To examine the effect sizes, the studies were first divided into four groups: primary school, secondary school, high school and university. According to measurements made based on Cohen's (1992) classification, studies carried out at primary school (ES=1.222) and university (ES=0.857) level had large effect size, studies at high school (ES=0.307) and secondary school (ES=0.406) level had medium effect.

Table 2. The effect of sizes of studies regarding school stages

Groups	n	ES	Effect size and 95% confidence interval		Test of null		Heterogeneity		
			Lower	Upper	Z-value	P-value	Q-value	df	P-value
Primary School	9	1.222	0.958	1.485	9.089	0.000			
Secondary School	26	0.406	0.290	0.522	6.862	0.000			
High School	5	0.307	-0.174	0.787	1.250	0.211			
University	4	0.857	0.443	1.270	4.062	0.000			
Tot. Betw.	44	0.547	0.447	0.648	10.667	0.000	33.977	3	0.000

When the between-groups test of homogeneity obtained from the results of meta-analysis and given in Table 2 is examined, it is seen that Q_B=33.977. $\chi2$ is calculated as $\chi2$ = 7.815 at 95% significance level and 3 degree of freedom ($\chi2_{(0.95)}$ = 7.815). Accordingly, it was seen that the statistical value of Q_B (Q_B=33.977) was bigger than critical value of $\chi2$ distribution ($\chi2_{(0.95)}$ = 7.815). Therefore, it can be said that the distribution is heterogeneous. On the other hand, when between-groups effect size in grouping made based on school stages is examined (Q_B=33.977; p=0.00), significant difference was found between groups (Z=10.667, p=0.00). This finding indicates that academic achievement level in classes carried out using STEM practices changes depending on school stage.

The Efficiency of STEM Practices Based on the Implementation Period of the Study

In the analysis on the effect size of STEM practices, period of implementation of the studies was chosen as another moderator. In this context, in order to determine whether the effect size of STEM practices change depending on the period of implementation, the implementation periods of the studies was grouped as 2-4; 5-6; 7-8; 9-+ weeks and "unknown". When the results from these five groups are analysed on Table 3, it is seen that according to Cohen's (1992) classification, they have medium (0.361), medium (0.597), medium (0.562), large (1.071) and small (0.254) effect size, respectively.

Table 3. The effect sizes of studies regarding implementation period

Groups	Effect size and 95% confidence interval				Test of null		Heterogeneity		
	n	ES	Lower	Upper	Z-value	P-value	Q-value	df	P-value
2-4	3	0.361	0.019	0.702	2.071	0.038			
5-6	7	0.597	0.390	0.804	5.649	0.000			
7-8	5	1.562	0.286	0.838	3.986	0.000			
9-+	15	1.071	0.812	1.330	8.109	0.000			
Unspecified	14	0.254	0.127	0.380	3.939	0.000			
Tot. Betw.	44	0.459	0.368	0.549	9.956	0.000	34.231	4	0.000

Between-groups test of homogeneity shows Q_B=34.231. $\chi2$ is calculated as $\chi2$ = 9.488 at .05 significance level and 4 degree of freedom ($\chi2$ = 9.488; Q_B=34.231). In this case, it can be said that the distribution is heterogeneous. Accordingly, when between-groups effect size in grouping made based on implementation periods is examined (Q_B=34.231; p=0.00), significant difference was found between groups. On the other hand, as there were small number of studies with 2-4 and 7-8-week implementation, instead of making a certain judgement, information was given on the existing situation. Therefore, it is possible to say that academic achievement level in classes carried out using STEM practices changes depending on implementation periods. There is an important method to ensure reliability in meta-analysis studies. Indeed, in meta-analysis, the fact that the studies included in analysis are the ones with significant difference, in other words, they are the ones chosen among only published studies, create publication bias. Therefore, fail-safe number, which reduces this bias or removes it completely, is calculated (Rosenthal, 1979). In this study, following the analysis carried out, it was calculated that in the case that 5.1640 more studies on the impact of STEM on academic achievement are included, the mentioned significance will drop down to zero. When the number of studies included in the analysis is considered, it is seen that the fail-safe number reached is quiet high. In this case, as it is seen that the number of studies to be reached is too high that it is not possible to reach them all, it is possible to say that publication bias does not influence effect size (Cheung & Slavin, 2011). This finding, on the other hand, indicates that meta-analysis procedures are highly reliable. Another way of ensuring the reliability in meta-analysis studies is to calculate normal-quantile plot calculation as given in Figure 2. Thus, the studies included in the analysis should be between the two lines in the graphic. In Figure 2, each study is shown as a dot and these dots are between the two lines. This indicates that the effect size of the studies in the graphic has a normal distribution and the distribution is reliable (Rosenberg, Adams & Gurevitch, 2000). Therefore, it is once again understood that the analysis made towards STEM are reliable.

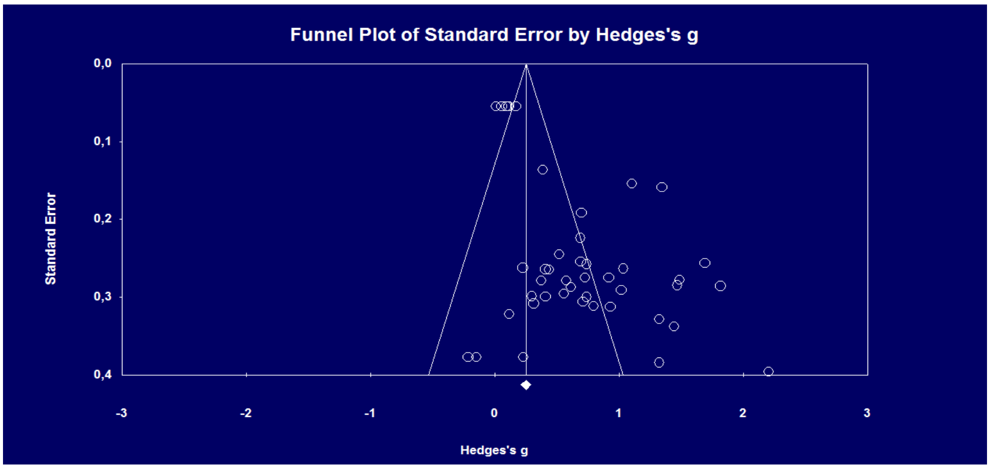

Figure 2. Funnel plot

Findings on the Efficiency of STEM within the scope of Thematic Analysis

In this research, in addition to meta-analysis, meta-thematic analysis was carried out to reach stronger and extensive results. This section includes the presentation and interpretation of the data collected through meta-thematic analysis based on document analysis. The themes and codes reached as a result of the analysis are given as models. It is seen that relevant codes are grouped under six themes and visualized in six models (Figure 3, 4, 5, 6, 7, 8). The titles of these themes are presented as the overall features of STEM practices (Figure 3), contribution of STEM practices to cognitive domain (Figure 4), contribution of STEM practices to affective domain (Figure 5), contribution of STEM practices to individual efficiency and personal development (Figure 6), contribution of STEM practices to skills development (Figure 7) and difficulties encountered in practice (Figure 8).

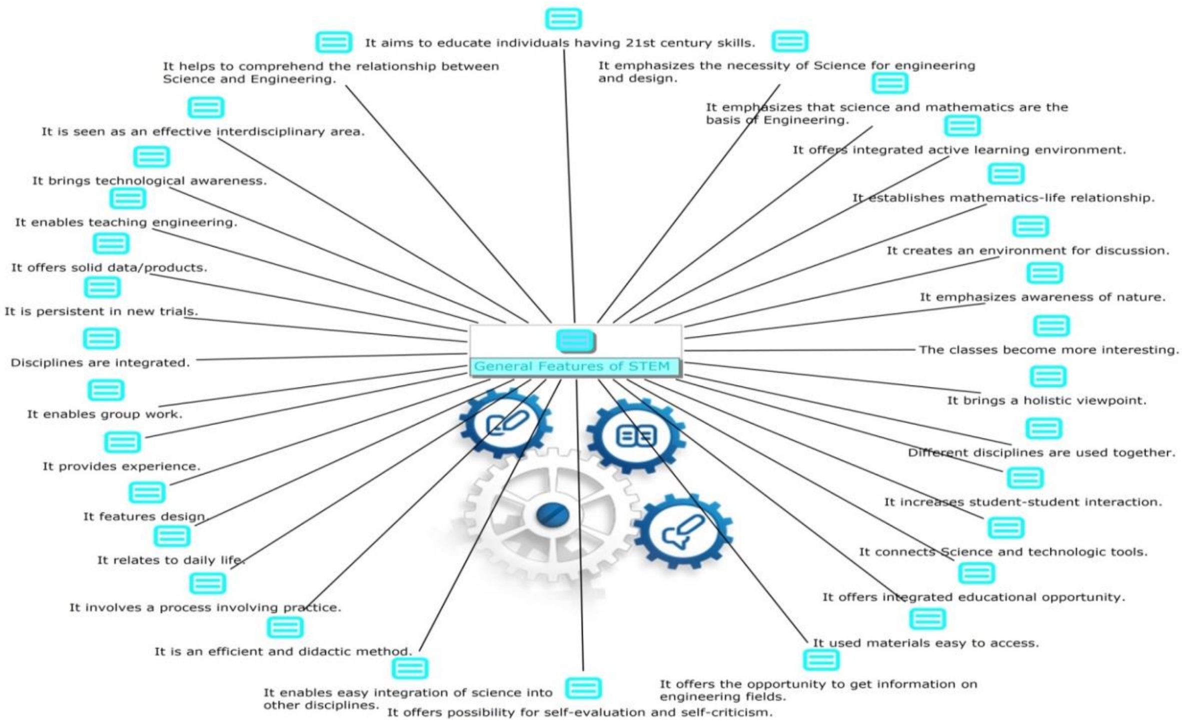

Figure 3. General features of STEM

Among the codes mentioned in the context of general features of STEM practices given in Figure 3 are "The fact that it emphasizes that science and mathematics are the basis of Engineering, the fact that it offers solid data/products, the fact that different disciplines are used together, the fact that it offers integrated educational opportunity, the fact that it offers integrated active learning environment, the fact that it aims to educate individuals having 21st century skills, the fact that it establishes mathematics-life relation and that it emphasizes awareness towards nature". In the context of this theme, the citations from 480179-p.37 and 513968-p.108, which were "*it helped to understand that Science, Mathematics, Technology and Engineering are not unconnected to each other and that they are in almost all areas of our daily life*" and "*…it aims to educate individuals having 21st century skills. It brings in such skills as being independent, looking at things from different points of view, being in cooperation and communicating.*", respectively were taken as references and used while creating the codes. Relevant reference sentences show that such skills as making discoveries, developing products, designing, asking questions and sharing can be revealed and reinforced through STEM activities.

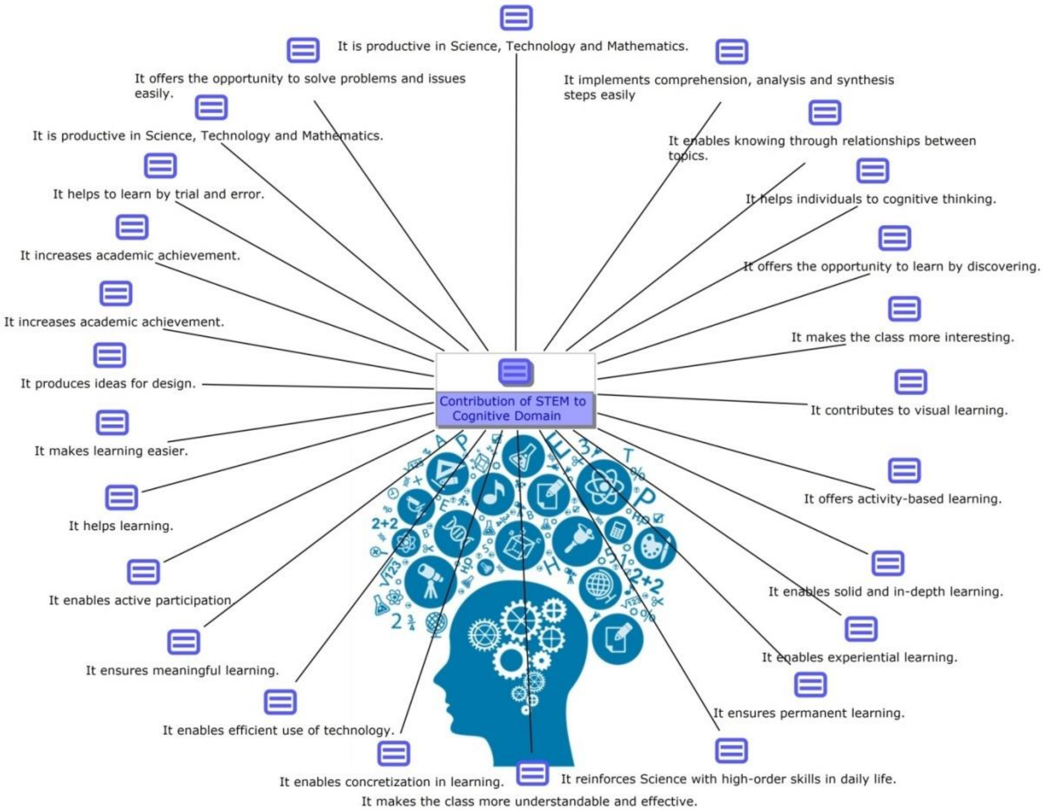

Figure 4.Contribution of STEM to cognitive domain

When Figure 4 is examined, it is seen that codes related to the contribution of STEM practices in cognitive dimension are given in the model. Among the codes related to this model are "that it increases academic achievement, ensures active participation, that it implements comprehension, analysis and synthesis steps easily, that it helps individuals to cognitive thinking, that it enables solid and in-depth learning, that it makes the class more understandable and effective, that it makes learning easier and that it ensures meaningful learning". Among the expressions taken as reference while creating the codes are "*It does not stop at knowledge-comprehension steps but carries the learner to the analysis and synthesis steps easily.*" from the study coded 513968-p.109 and "*I believe that when the classes are taught with STEM activities, it brings more advantages compared to other learning methods. What is learned will be more permanent.*" from the study coded 480179-p.36. These expressions clearly show that STEM education is related to Bloom's taxonomy. In fact, the purpose in the analysis, synthesis and evaluation steps is to show high-order cognitive behaviours. Since STEM education aims to develop behaviours to realize these steps, it is necessary to implement this approach in our country in a right and planned manner.

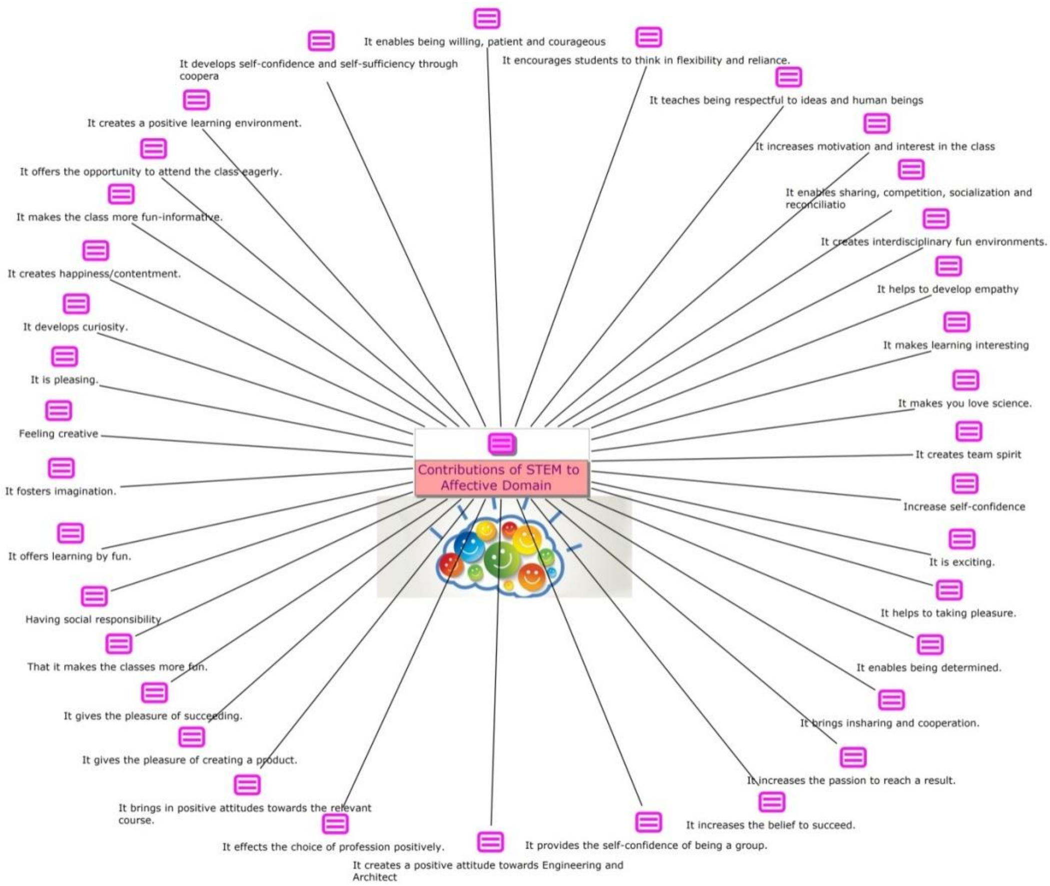

Figure 5.Contributions of STEM to affective domain

Figure 5 shows the codes related to the contributions of STEM practices to the classroom environment. Among these contributions are: "that it effects the choice of profession positively, that it fosters imagination, that it develops curiosity, that it creates a positive attitude towards Engineering and Architecture, that it makes the class more fun- informative, that it offers learning by fun, that it creates contentment and happiness and that it creates the pleasure of succeeding". The expressions that could be reference to these codes are "*…These activities made me love science. I believe that these activities direct people to engineering and develop positive attitudes towards engineering…*" from the study coded 529253-p.87. In addition, the sentences: *…it will increase motivation of the students towards the class and this will increase students' success in the class*" from the study coded M7-p.378 can be given as sources used while creating the codes. After examining the codes, it is possible to say that STEM education could help to create a student profile who are curious, interested and willing; and that this profile could lead to encouraging skilled students to Science, Technology, Engineering and Mathematics.

Figure 6 shows the codes related to the contributions of STEM practices to individual competencies and personal development. Among these codes are: "that it fosters productivity, that it contributes to the development of intelligence and personal development, that it brings in research and analytical thinking skills, that it emphasizes all-round development, that it emphasizes the development of technological skills, that it brings in scientific and different perspectives, success of self-expression, that it enables the development of visual memory and helps the development of relationships between friends". Among the expressions used as source while forming these codes are: "S*TEM is a conception which helps students to develop solutions to problems, to examine an object from different perspective and a conception which I believe will be necessary for the development of the society…*" from the study coded 513968-p.108. These codes indicate that students could be equipped with the skills to make individual and group work, to make research, discoveries and produce projects with an interdisciplinary approach.

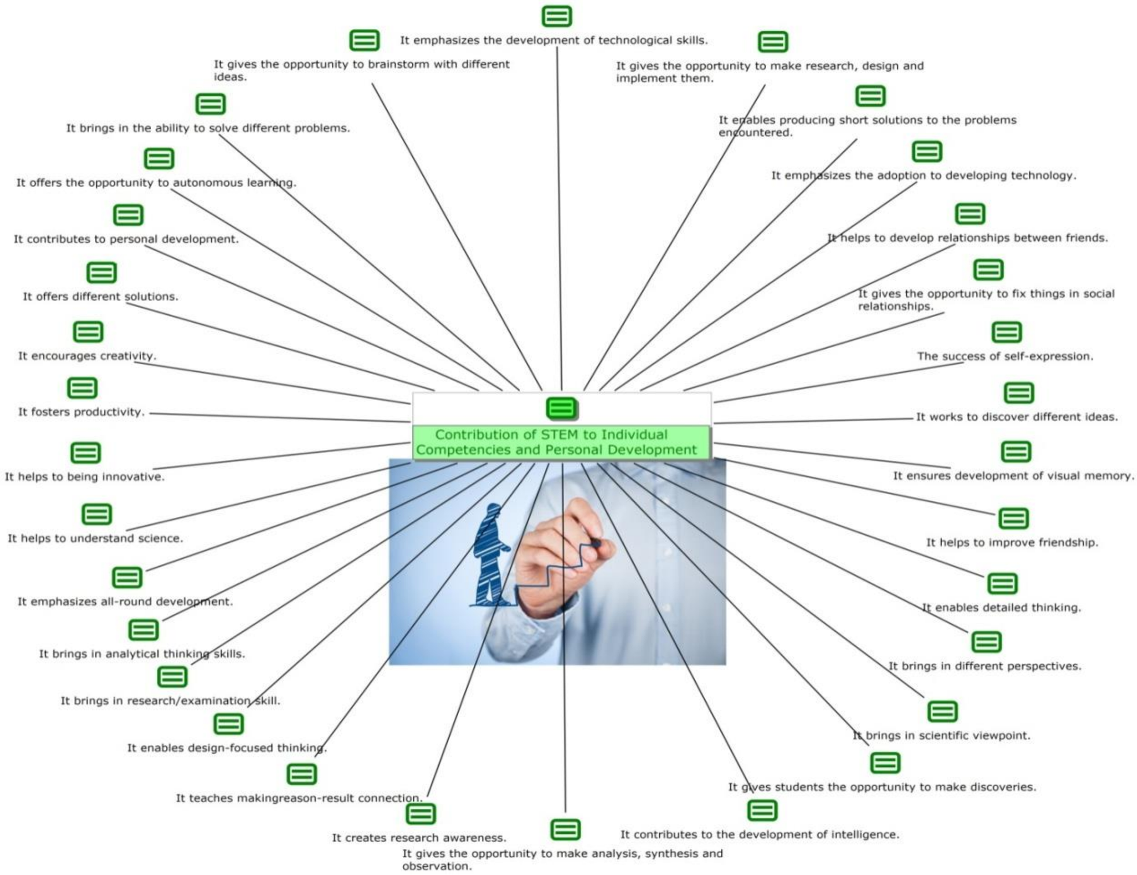

Figure 6.Contribution of STEM to individual competencies and personal development

When Figure 7 is examined, it is seen that codes related to the contribution of STEM practices to skills development are formed.

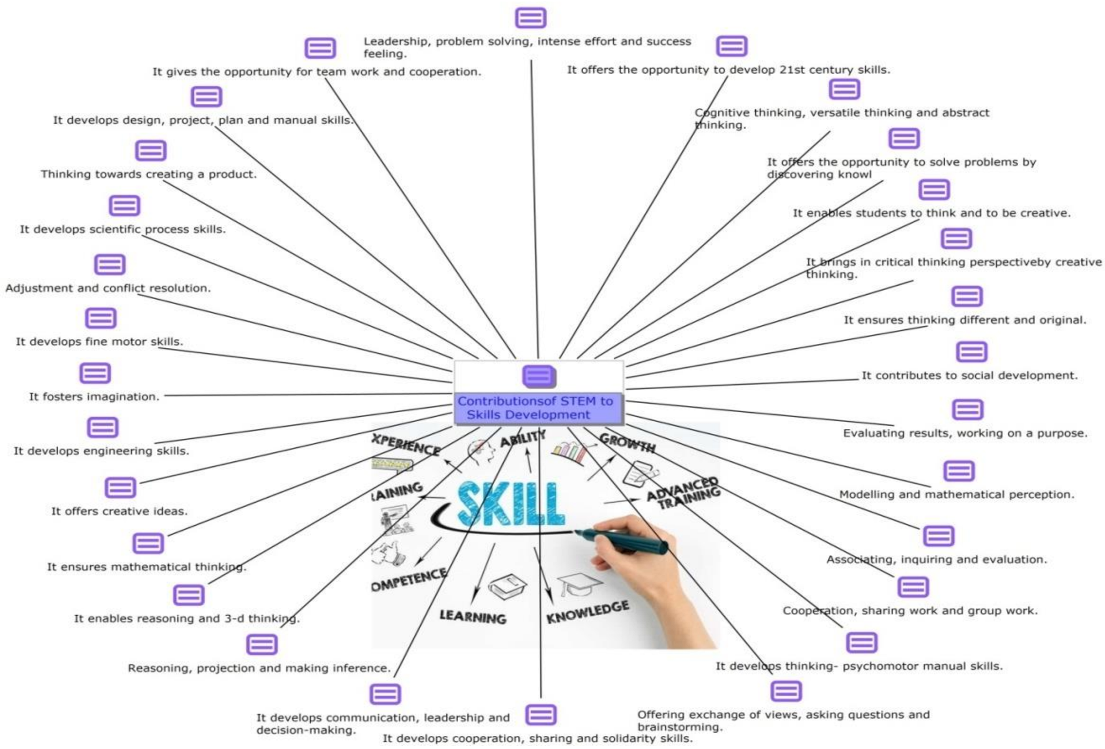

Figure 7.Contributions of STEM to skills development

Among the codes formed on this model are: "that it develops thinking- psychomotor manual skills, that it develops design, project, plan and manual skills, that it develops fine motor skills, that it offers the opportunity to develop 21st century skills, that it develops engineering skills, reasoning, projection and making inference and that it develops scientific process skills". While forming the codes expressions "*Their manual skills developed. Their thinking skills improved. It helped them to develop creative thinking, producing an original design and developed their self-confidence.*" from the study coded 506186-p.61 were used. Therefore, it is possible to say that with STEM activities, it is easier to equip students with such 21st century skills as research and flow of information, communication and cooperation, creativity and innovation, critical thinking and problem solving and equipping students with technology using skills.

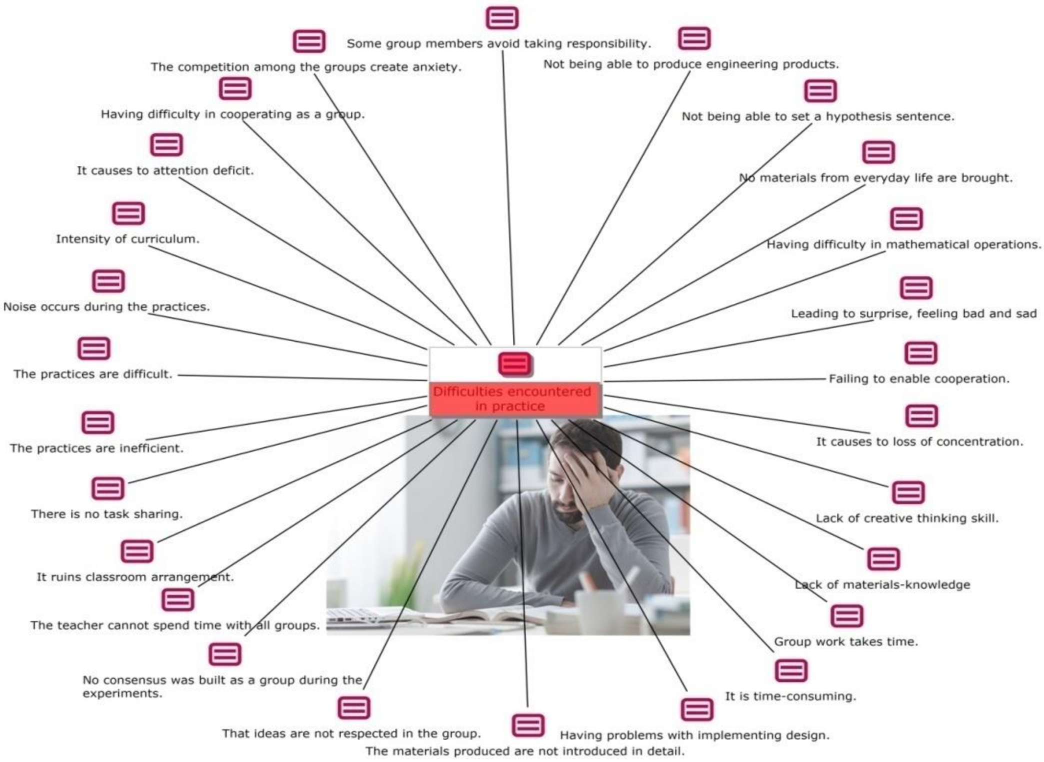

Figure 8. Difficulties encountered in practice

When Figure 8 is analyzed, it is seen that the difficulties encountered during STEM practices are highlighted. Among the codes under this figure are: "that the practices are difficult, that the teacher cannot spend time with all groups, thatthe materials produced are not introduced in detail, that it is time consuming, lack of material-information, not being able to produce engineering products, having difficulty in using technology, having difficulty with implementing design, leading to surprise, feeling bad and sad". Relevant codes are formed based on: "*…there is a time issue in the class… that students cannot get organized…*" from study coded 506186-p.61 and "*…There has been some problems with working in harmony in a group. Because some people made fun of others' ideas. This caused to troubles in design…*" from the study coded 527233-p.78. The content of the codes includes that STEM causes to some troubles in terms of technology. It is believed that on condition that necessary technical equipment is provided, this issue could be solved. On the other hand, the problem with timing could be about planning. It is projected that no big problems and setbacks will occur in a planned and well-prepared implementation, where the possible problems are projected beforehand, necessary precautions are taken and possible solutions are thought.

Conclusion and Recommendations

This study includes meta-analytical and meta-thematic evaluations on the use of STEM activities and practices in educational environments. 26 studies were included in the meta-analysis in line with the purpose of the study. When the findings reached as a result of meta-analysis are examined, it is seen that STEM has a significant and positive impact on academic achievement at medium level (ES=0.655). This result indicates that STEM-based activities and practices are efficient in increasing students' academic achievement. At this point, Büyükdede (2018) explained the reasons of how STEM education, a holistic approach, effects students' academic achievement in a positive direction, that: (i) STEM is a student-centered approach, (ii) it allows students to design projects/products using what they learn (iii) that it guides students to research and question and (iv) it equips students to discover that they can produce are some of these reasons. As a result, it is possible to express that STEM education offers a rich learning environment; it has positive impacts on students' learning and effect academic achievement in a positive direction. In addition to that, it can also be indicated that STEM practices increase students' achievement because it ensures meaningful learning and because it creates a process in which students are responsible from their own learning (Eroğlu & Bektaş, 2016). This result in relevant research matches with the result we got (increase in academic achievement) in meta-analysis. Therefore, it is possible to say that the results from this study are supported with the relevant literature. On the other hand, in meta-analytical evaluation, moderator analysis was used to see whether STEM efficiency changed depending on grades and period of implementation. The findings revealed that STEM education changed depending on grades and periods of implementation. Accordingly, it is possible to say that the effect level of STEM education changes depending on the school stage or the period of implementation. As a result of calculating the publication bias (fail-safe number) which ensures the reliability of the meta-analytical study and after checking whether the effect sizes of the studies had a normal distribution, it was seen that there was nothing unfavorable. This result indicates that the analyses in both calculations are reliable.

Within the scope of the research, in addition to meta-analysis, meta-thematic analysis was carried out and themes and codes were formed on the impact of STEM practices in different domains. At this point, when the codes on the *general features* of STEM are examined, it is seen that some results similar to what already exists in the literature are found. These results are: STEM is a holistic education system, it aims to equip students with 21st century skills, it offers an active learning environment and thus, it makes classes more interesting by offering a didactic method (Aygen, 2018; Ensari, 2017). In addition, STEM education is based on integrating Science, Engineering and Mathematics with technology and correlates these disciplines with one another and thus, contributes to the formation of an interdisciplinary effective domain (Aygen, 2018; Meng, Idris &Kwan, 2014). At this point, it can be said that by enabling the classes to be delivered with an interdisciplinary approach, STEM makes it possible to view the teaching process with a holistic approach perspective.

Another finding from this study is the contributions of STEM to the *cognitive domain*. Among the contributions of STEM to this domain are easy implementation of high-order cognitive skills such as analysis and synthesis in the learning process, the fact that it offers the opportunity to easily solve problems and cases, that it contributes to visual learning and the fact that it makes learning easier. A similar finding could be that STEM education offers experiential learning and thus, makes the class more interesting and understandable. As a result, meaningful and permanent learning is ensured (Alıcı, 2018; Ensari, 2017; Özçakır Sümen, 2018).

Another issue examined in the study was the contribution of STEM education to *affective domain*. It was found that STEM improved the feelings of curiosity, willingness, interest towards the class, the pleasure of succeeding, excitement and determination, sharing and collaboration. Similar findings exist in the literature. To set an example, one study found that STEM education enabled students to make interdisciplinary connections and increased students interest and motivation towards the class (Watthananon, 2015). In addition, it was also found in other studies that STEM encouraged students to choose Science and Engineering disciplines as profession, developed their 21st century skills and helped them to use these skills (Özmen, 2018). It was also found that STEM education associated different disciplines and skills and integrated them, and accordingly, it made classes more interesting and different and thus, created a positive learning environment and made the learning process fun, active and efficient (Acar, Tertemiz & Taşdemir, 2018; Ensari, 2017). It was found that STEM could increase many characteristics of the students including learning motivation, creativity, curiosity, responsibility, imagination, belief in their capability, self-confidence and empathy and students could boldly make interdisciplinary knowledge transfer.The fact that the results from the current study are similar to the results of relevant studies make the results of this study strong and reliable.

Another theme on the efficiency of STEM education in the learning process was finding out the contribution of STEM under *individual efficiency and personal development* domain. Among the most outstanding codes under this topic in the study were all-round development, research, design, production, using technology etc. It can be said that in terms of associating more than one discipline and bringing them together, STEM education guides individuals to disciplines they are interested in and contributes to their personal development by using other disciplines (Aygen, 2018). It was also indicated in some studies that STEM education had a positive effect on the development of students' decision making, analytical thinking and fine motor skills, brought in scientific and different points of view and offered the opportunity to make research, design and implementation (Bozan, 2018). All the given results and comments could indicate that STEM could bring in the skills and competences necessary to respond to the knowledge, power and technology need required in this century and will be required in the future.

Another finding in the study was the contribution of STEM to *skills development*. When relevant codes were examined, it was seen that many expressions including associating, reasoning, projection, acquiring scientific process skills, discovering knowledge, social development, solidarity etc. were mentioned within the scope of skill. At this point, it is indicated in the literature that STEM was effective in equipping students with such 21st century skills as thinking different and original, producing creative ideas, critical thinking, discovering knowledge and problem solving and turning dreams into products (Şentürk, 2017). Another study found that STEM education had a positive impact on students due to such reasons as offering the opportunity forteam work, solidarity, cooperation and collaboration, developing communication, decision-making, leadership and feeling of achievement (Alıcı, 2018). It was also seen that STEM education improved mathematical skills and competences in different domains such as reasoning, 3-d thinking, inquiring, associating, deduction and analysis-synthesis (Özçakır Sümen, 2018). Aforementioned positive contributions of STEM are interpreted as it effects the development of different skills. This indicates that the results from this study are supported by the studies given above.

In addition to the aforementioned contributions of STEM, which helps learning by developing different features of the individuals, some *difficulties* encountered during practice were found. Such cases as the fact that the teacher cannot spend time with all groups during practice, there are difficulties encountered during practice, it is time consuming and the class deviates from its aim could cause to ruining of classroom arrangement, inefficiency of the practice and loss of the desired efficiency from the class. In addition, lack of materials and knowledge, lack of introduction of the materials in detail and problems in using technology were also remarkable. However, it is necessary to implement STEM power, which we need and most probably will continue to need in the future, in a planned and systematic way with the cooperation of the government and education community. The success of a more effective, efficient and problem-free practice will certainly be higher. Therefore, a fully-equipped environment, where practice is carried out thoroughly, necessary precautions are taken and solutions are offered, will certainly reach the target. Hence, with necessary planning and regular practices STEM education will repay the investments made. However, to implement this approach in an efficient way, the disadvantages found by existing studies should be removed and more systematic practices should be implemented. On the other hand, there are no studies on STEM carried out in the form of meta-analysis. Moreover, there are no studies carried out with a meta-thematic aspect. Therefore, it is suggested that both quantitative (meta-analysis) and qualitative (meta-thematic) studies should be carried out to attract attention to the topic and increase awareness of the readers.

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Author Information

Veli Batdi
Kilis 7 Aralık University, Muallim Rıfat Education Faculty, Department of Curriculum and Instruction, Kilis
Turkey
Contact e-mail: *veb_27@hotmail.com*

Tarık Talan
Gaziantep Islam, Science and Technology University, Faculty of Engineering and Natural Sciences, Gaziantep
Turkey

Çetin Semerci
Bartın University, Deanery of Education Faculty, Bartın
Turkey

Appendix-1. The Cappa Statistic Values of Qualitative Aspect of the Study

		General Features					Cognitive Domain					Affective Domain					Personal Development		
		K2					K2					K2					K2		
		+	-	Σ			+	-	Σ			+	-	Σ			+	-	Σ
K1	+	30	4	34	K1	+	22	2	24	K1	+	35	15	40	K1	+	31	4	35
	-	5	26	31		-	3	17	20		-	4	26	30		-	3	21	3
	Σ	35	30	65		Σ	25	19	44		Σ	39	31	70		Σ	34	25	59
Kappa: .722			**p:.000**		Kappa: .770			p:.000		Kappa: .739			p:.000		Kappa: .756			p:.000	

		Skills Development					Difficulties encountered in practice		
		K2					K2		
		+	-	Σ			+	-	Σ
K1	+	28	3	31	K1	+	27	2	29
	-	2	19	21		-	1	16	17
	Σ	30	22	52		Σ	28	18	46
Kappa: .802			**p:.136**		Kappa: .862			p:.000	

Appendix-2. The Meta-analysis Data Collection Form

Author and Year	Grade/ Class	Course/ Field	Duration of Application (Weeks)	N	Effect size	Results/ Conclusions
Abdullah N, Halim, L., & Zakaria, E. (2014)	Primary School	Mathematics	10	193	1.103 1.347	+
Acar, D., Tertemiz, N., & Taşdemir, A. (2018)	4th grade	Science and Mathematics	13	43	1.446 0.796	+
Aygen, M. B. (2018)	University	Biology	Unspecified	65	1.489	+
Bilekyiğit Y. (2018)	10th grade	Biology	12	51	0.374	+
Büyükdede, M. (2018)	University	Physics	5	69	0.520	-
Çalışıcı, S. (2018)	8th grade	Science	8	44	0.930	+
Doğanay, K. (2018)	7th grade	Science	10	40	2.206	+
Gazibeyoğlu, T. (2018)	7th grade	Science	6	52	0.575	+
Gülhan, F. (2016)	5th grade	Science	12	55	0.728	+
Gülhan, F., & Şahin, F. (2018)	7th grade	Science	5	63	0.737	+
Karcı, M. (2018)	5th grade	Science	4	50	0.613	+
Koca, E. (2018)	7th grade	Science	Unspecified	33	1.326	+
Nağaç, M. (2018)	6th grade	Science	4	44	0.298	-
Özçakır Sümen, Ö. (2018)	University	Mathematics	12	46	0.740	+
Renee Mckinnon, F. (2018)	5th grade	Science	Unspecified	1337	0.111 0.170 0.007 0.094 0.114 0.057	-
Robinson, A., Dailey, D., Hughes, G. & Cotabish, A. (2014)	Elementary gifted students	Science	9	284	0.691 0.699 1.819 1.694 1.467	+
Sarıcan, G. (2017)	6th grade	Science	5	44	0.408	-
Şahin, A., Oren, M., Willson, V., Hubert, T. & Capraro, R. M. (2015)	9th grade through 11th grade	Science and Mathematics	Unspecified	106	0.230 -0.150 -0.215	-
Şentürk, F. K. (2017)	7th grade	Science	6	52	1.019	-
Yıldırım, B., & Altun, Y. (2015)	University	Science	Unspecified	83	0.689	+
Yıldırım, B. & Selvi, M. (2017)	7th grade	Science	Unspecified	78	1.325 0.710	+
Neccar D. (2019)	6th grade	Science	4	37	0.116	-
Kurtuluş M. A. (2019)	6th grade	Science	7	85	0.408 0.918 0.226 0.436	+
Irak M. (2019)	5th grade	Science	22 lesson hours	57	0.387	+
Özdemir H. (2019)	11th grade	Mathematics	1 term	64	1.035	+
Dumanoğlu F. (2018)	7th grade	Science	6	88	0.558 0.314	-

+: STEM applications had positive effects.
-: STEM applications had no positive effects.