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The Effects of Integrated STEM Education Practices on Problem Solving Skills, Scientific Creativity, and Critical Thinking Dispositions

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Today, the need for individuals who follow scientific and technological developments closely and who can adapt to these changes rapidly is increasing. These needs have made it necessary for countries to try various changes, reforms and current approaches required by the age in their education systems. One of these approaches is STEM education, which has frequently been encountered in the national and international literature in recent years. STEM (science, technology, engineering, and mathematics) education is an approach that emphasizes the 21st century skills, integrates science, technology, engineering, and mathematics disciplines, and covers formal and informal education at all education levels. In addition, the number of studies on STEM education is increasing daily. This research aims to integrate the 8th-grade science curriculum with STEM education practices and examine the effects of these practices on students' problem-solving (PS) skills, scientific creativity, and critical thinking dispositions. In this study conducted with quantitative methods, the pretest-posttest control group design of the quasi-experimental method was used. The study group of the research consists of students who took the 8th-grade science course at a private school. Research data were collected from both the classes before and after the experimental study. Descriptive statistics and covariance analysis (ANCOVA) were used in the data analysis. The research results revealed that integrated STEM education applications positively affect students' problem-solving skills, scientific creativity, and critical thinking dispositions. The collected results were discussed with the studies in the literature, and suggestions were made accordingly.

Introduction

The human profile in the 21st century requires individuals with high-level thinking skills, can solve problems, have a critical perspective, are open to innovations, are productive, creative, and cooperative (Kay, 2010). Hence, the need for individuals who follow scientific and technological developments closely and can adapt to these changes rapidly is increasing

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day by day. These needs have necessitated the reforms and current approaches required by the age in the education systems of the countries (Becker & Park, 2011). One of these approaches is STEM education, which has become widely popular among researchers in the national and international literature recently (Admiraal et al., 2019; Chen et al., 2021; Donohue, 2020; Kelly, 2022; Kim et a., 2021; Kocsis, 2022; Wan et al., 2021).

Science, technology, engineering, and mathematics education, originally abbreviated as STEM (Science, Technology, Engineering, and Technology) and translated into Turkish as *FeTeMM* (Corlu et al., 2012), was first introduced in the 1990s (Sanders, 2009). Later, when it was brought up again by Dr. Judith Ramaley in 2001, it attracted the attention of many researchers (Bybee, 2010, English, 2016; Thibaut et al., 2018). Finally, the interest in STEM peaked with the "Next Generation Science Standards" study published in the USA in 2013 (Yager & Brunkhorst, 2014).

STEM education has been one of the most remarkable educational movements in education in recent years (Kuenzi, 2008; Sanders, 2009). In this context, STEM education has strategic importance for countries to have a say in international rivalry (Corlu et al., 2014). STEM education highlights three main topics (problem-solving, innovation, and design) on every country's agenda (Hernandez et al., 2014). The disciplines that make up STEM education are essential for gaining 21st-century skills (Bybee, 2010). Morrison (2006) argues that individuals raised with STEM have the skills required by the age, such as problem-solving (PS), critical thinking (CT), and scientific creativity (SC).

STEM education is a multidisciplinary approach that aims to provide students with a holistic education in STEM disciplines (Doganca Kucuk et al., 2021; Morrison, 2006; Saricam & Yildirim, 2021), which also supports many educational movements in the contemporary world (Capraro et al. al., 2016; Daugherty, 2013; Preuss et al., 2020). There is no standard definition in the literature on STEM education (Langdon et al., 2011). However, there is a consensus in the relevant literature that STEM education is an approach to science, technology, engineering, and mathematics disciplines (Batdi et al., 2019; Benek & Akcay, 2019; Bybee, 2010; Wannapiroon et al., 2021).

STEM education can be classified into two: traditional STEM education and integrated STEM education (Sanders, 2009). While traditional STEM education focuses on the STEM disciplines independently from each other, integrated STEM education integrates STEM disciplines and makes them interconnected (Akgündüz et al., 2015; Sanders & Wells, 2010; Yılmaz et al., 2017). Many researchers recommend integrated STEM education dues to its student-centered structure (National Research Council [NRC], 2009). Until the 2000s, STEM education was perceived as equivalent to the quartet of discrete disciplines from Bybee's (2013) models, but today it is used more in integrated disciplines (Ring, 2017). Morrison (2006) defined STEM education as a meta-discipline that creates a new whole by integrating knowledge from different disciplines. He also states that STEM education creates a new understanding with a supra-disciplinary approach.

The literature review suggests that the number of studies on STEM education has gradually increased (Chine & Larwin, 2022; Marco-Bujosa, 2021; Punzalan, 2022; Razi & Zhou, 2022; Reynders et al., 2020; Talan, 2021; Turner et al. al., 2022; Wang et al., 2022). Since studies are generally suitable for the nature of the course, they are carried out in science courses or courses of a similar nature (Ceylan, 2014; Nağaç, 2018; Pekbay, 2017). Besides, Bybee (2010) indicates that integrating other STEM disciplines into science and mathematics courses in the K-12 curriculum is the most reasonable way. This research integrates integrated STEM education practices with the middle school 8th-grade science curriculum. In this context, this study attempts to integrate the education and teaching process with STEM education in line with the objective of the current curriculum to ensure the effectiveness of STEM education practices. To this end, the units of "Reproduction, Growth, and Development in Humans / Living Things and Life," "Simple Machines / Physical Events," "Structure and Properties of Matter / Matter and Change," and "Light and Sound / Physical Events" in the curriculum are examined based on the effects of integration with STEM education on students' PS skills, SC levels, and CT dispositions. It is predicted that this research, which was developed based on STEM education, could guide new research that will be beneficial to science education researchers, teachers willing to prepare textbooks or course materials, students, and prospective teachers.

Theoretical Framework

STEM Education

According to Williams (2011), STEM education is an approach in which engineering and technology are used jointly to improve mathematics and science learning. Corlu et al. (2014), on the other hand, define STEM education as integrating the knowledge and skills of a major discipline, shaped by the experiences of students and teachers, with at least one STEM field. Considering the current definitions, STEM education can be described as an approach that puts the student in the center, prioritizes collaborative learning, provides the integration of science, technology, engineering, and mathematics disciplines, and covers formal and informal education in all age groups from preschool to higher education (Herschbach, 2011; Israel et al., 2013).

STEM education focuses on 21st-century skills and contributes to acquiring these skills. Raines (2012) states that a country's ability to compete with other countries depends on the number of specialist individuals in the field of business with STEM skills. To raise such individuals, the need for education systems that give individuals responsibility, canalize them to think, equip them with up-to-date information such as information and communication technologies from an early age, and provide individuals with an entrepreneurial and creative spirit as well as PS skills continues to increase day by day (Akgündüz et al., 2015; Karisan et al., 2019; Keskin et al., 2020).

STEM education is discussed under two headings as traditional STEM education (Figure 1) and integrated STEM education (Figure 2) (Guzey et al., 2014; Sanders, 2009). Traditional STEM education is an approach that is frequently used in modern education systems. In traditional STEM education, STEM disciplines are independent of one another (Yılmaz et al., 2017). In integrated STEM education, the theoretical knowledge revealed by science and mathematics is integrated with technology and engineering applications (Akgündüz et al., 2015; Sanders & Wells, 2010).

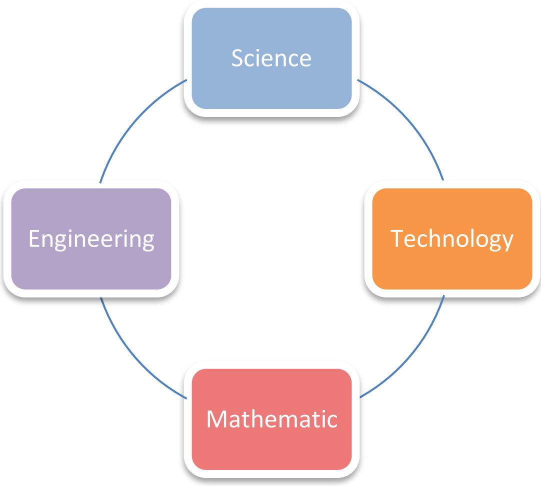

Figure 1. Traditional STEM Education

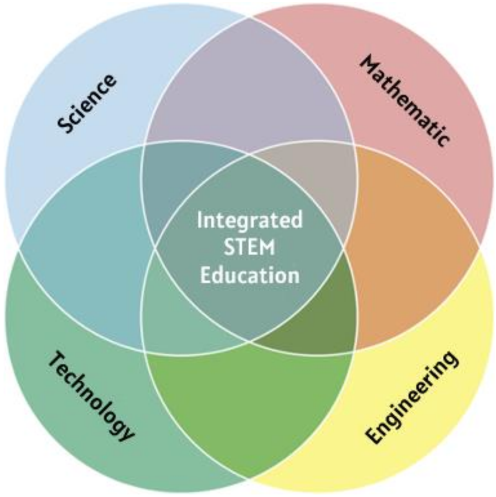

Figure 2. Integrated STEM Education

Integrated STEM Education

Integrated STEM education has a student-centered structure (NRC, 2009). Integrated STEM education is defined as establishing a connection by creating an integration instead of teaching the fields that make it up separately. Effective integration of STEM disciplines has positive effects on academic achievement (Ceylan, 2014; Hartzler, 2000), willingness and interest in learning (Venville et al., 2000), and attitude towards the course (Yamak et al., 2014).

Various approaches have been adopted to realize STEM education (Bybee, 2013; Dugger, 2010; Sanders, 2009). The first approach is to consider all areas independently of each other. Another is to focus on one or two of the STEM fields (Sanders, 2009). Such an approach cannot meet expectations because it ignores technology and engineering (Bybee, 2010). Another approach is to integrate one of the STEM fields separately into the other fields. The use of engineering applications in science, mathematics, and technology courses can be given as an example of this situation. An alternative approach is to include other STEM fields within one of the STEM fields. Integration of mathematics, engineering, and technology within the scope of science can be given as an example of this type of approach (Dugger, 2010)

Problem Solving and STEM Education

PS is the ability of an individual to find solutions to daily life problems. The ability of the individual to bring solutions to the problems he encounters ensures his adaptation to the environment he lives in (Bağçeci & Kinay, 2013). It is a skill that should be acquired at an early age (Pekbay, 2017).

It is one of the vital subject areas of STEM education to confront individuals with the problems they may encounter in daily life and ensure the integration of more than one discipline in the solution to these problems (Williams, 2011). Howard-Brown et al. (2012) suggest that PS skills intersect with STEM disciplines.

Scientific Creativity and STEM Education

SC is a process that includes scientific PS stages (Hu & Adey, 2002). Creative thinking is of great importance to produce a compelling and original product in STEM education since it includes processes that encourage students to think creatively while producing solutions to problems (Charyton, 2015).

In STEM education, students constantly conduct research and ask a question, and they also use their skills such as making observations, designing experiments, and determining variables in various design studies (Yamak et al., 2014). In this respect, STEM education allows students to develop SC skills (Atabaş, 2020). In this context, it is important to consider all aspects of STEM education holistically in terms of the use and development of SC (Bebek, 2021).

Critical Thinking and STEM Education

CT is shown among crucial 21st-century skills along with PS and SC in many sources. CT is beyond rote learning, a set of mental activities that include analysis, evaluation, and reflective and creative thinking (Felder & Brent, 2016). Relevant mental activities are frequently used in STEM education.

Many studies in the literature indicate that STEM education positively affects CT skills and dispositions (Kuehnert et al., 2019; Reynders et al., 2020). The Turkish Industry and Business Association (2017) emphasizes that 21st-century skills such as CT and PS can be developed through STEM education, thus raising qualified individuals. Moreover, Morrison (2006) argues that STEM education develops high-level skills by using spatial abilities to solve problems.

Significance of the Research

Compared with the international literature, studies on STEM education in Turkey are insufficient in terms of quality and quantity. To this end, only 1.08% of the publications on STEM education on the Web of Science are of Turkish origin. Although the studies on STEM education at the national level in recent years have been at the secondary school level (Ceylan, 2014; Yamak et al., 2014), these studies include STEM applications developed independently of the objectives in the science curriculum. This research differs from many other studies in the literature because of the involvement of integrated STEM education practices in the secondary school science curriculum. In this sense, STEM integration was provided by considering the objectives in the current curriculum to decide on the effectiveness of the developed STEM education application. Besides, the research is expected to contribute to developing a comprehensive STEM curriculum.

The research is also of original value since three-dimensional printers are used in teaching activities. The research allowed students to make their designs in the computer environment three-dimensional with these printers. Thus, it is anticipated that students will contribute to developing PS, creative thinking, and CT skills. At the same time, it is thought to be important in transforming the knowledge in the field of science that students have learned theoretically into engineering applications and concrete products through STEM education activities.

Problem Statement

The problem statement of this research is, “Do integrated STEM education applications affect middle school students’ PS skills, SC, and CT dispositions?”

Sub-Problems of the Research

(1) Is there a significant difference between the PS inventory post-test scores of the experimental group in which integrated STEM education practices were applied and the control group?
(2) Is there a significant difference between the SC test post-test scores of the experimental group in which integrated STEM education practices were applied and the control group?
(3) Is there a significant difference between the UF/EMI CT disposition scale post-test scores of the experimental group in which integrated STEM education practices were applied and the control group?

Method

Research Model

Quantitative methods were used in this study. In this direction, the pretest-posttest control group design of the quasi-experimental method, frequently seen in studies in education, was used. In this design, matching is performed through ready-made groups. Matched groups were randomly assigned to the study groups. (Buyukozturk et al., 2013).

While integrated STEM education practices were applied in the experimental group, no intervention was made in the control group. The courses were taught according to the 2013 science curriculum, which was officially implemented at the time of this research. After the integrated STEM education applications, the measurement tools were applied as a pre-test to both groups were also applied as a post-test. The experimental model of the research is shown in Table 1.

Table 1. Experimental Model of the Research

Group	Pre-test	Activities	Post-test
Experimental Group	-PSIC -SCT -UF/EMI CTD	Integrated STEM Education Applications	-PSIC -SCT -UF/EMI CTD
Control Group	-PSIC -SCT -UF/EMI CTD	Appropriate for the Science Curriculum	-PSIC -SCT -UF/EMI CTD

Sample

The sample group of the study was determined by convenient sampling as one of the non-random sampling methods. The study group consists of students who took the 8th-grade science course of a private school in Konya city of Turkey. While the experimental group consists of 22 students, 12 females and 10 males, the control group consists of 22 students, 13 females and 9 males (see Table 2).

Table 2. Information on the Students in the Experimental and Control Groups

Groups	**Female**		**Male**		**Total**	
	N	**%**	**N**	**%**	**N**	**%**
Experimental Group	12	54.5	10	45.5	22	50
Control Group	13	59	9	41	22	50
Total	25	56.8	19	43.2	44	100

Both the experimental and control groups that make up the study group consisted of 22 participants. When the students in the experimental group are examined by gender, it is seen that 12 of them are female and 10 of them are male. The distribution of students in the control group is similar to the experimental group.

Formation of Experimental and Control Groups

Both experimental and control groups consist of 8th-grade students. Therefore, the students in the study group have similar age characteristics. During the interviews with the school administration and the science teacher, they expressed that the academic achievement levels of the two classes were similar. In order to prove the current situation statistically, whether the pre-test scores of the groups were equal or not was analyzed with MANOVA (Table 3).

Table 3. MANOVA Results on Pre-Test Scores of Experimental and Control Groups

Scale	**Groups**	**N**	$\bar{X}$	**SD**	**df**	**F**	**p**
PSIC	Experimental	22	81.72	7.50	1-42	0.63	0.42
	Control	22	83.18	4.06			
SCT	Experimental	22	44.40	9.57	1-42	3.65	0.06
	Control	22	39.00	9.19			
	Control	22	93.2	9.38			
UF/EMI CTD	Experimental	22	90.54	5.81	1-42	0.14	0.70
	Control	22	91.50	10.25			
	Control	22	10	1.95			

Table 3 indicates that the two groups were statistically equivalent before the integrated STEM education applications.

Data Collection Tools

Problem Solving Inventory for Children at the Level of Primary Education (PSIC)

PSIC is a valid and reliable measurement tool developed by Serin et al. (2010) that reveals the perception levels of middle school students about PS skills. The Cronbach’s alpha reliability coefficient of the scale is 0.85 in the confidence factor in problem-solving ability, 0.78 in the self-control factor, 0.66 in the avoidance factor, and 0.80 when calculated in general.

Scientific Creativity Test (SCT)

The SCT was developed by Hu and Adey (2002) and adapted into Turkish by Kadayıfçı (2008). SCT, which consists of seven open-ended questions in total, is based on the "Scientific Structure Creativity Model" and is a valid and reliable measurement tool that measures various dimensions of this model. The Cronbach's alpha reliability coefficient of the test, which has a single factor structure, is 0.73.

UF/EMI Critical Thinking Disposition Instrument (UF/EMI-CTDI)

UF/EMI-CTDI is a valid and reliable measurement tool developed by University of Florida researchers (Irani et al., 2007) that includes fewer factors and measures students' CT dispositions. The instrument was adapted to Turkish by Ertaş Kılıç and Şen (2014). The Cronbach's alpha reliability coefficient of the scale, which has 24 items and a 4-factor structure, is 0.89.

Experimental Design Process

The experimental research was carried out in the 8th-grade science course in two different classes in the first semester of the 2017–2018 academic year. For the process to run smoothly, teacher guide forms and student activity sheets have been designed. Expert opinions were obtained during the development process of the forms. The forms were designed to cover the 5E and 5D model processes based on the "STEM: Integrated Teaching Framework" and "STEM Circle" suggested by Çorlu and Çallı (2017). During the determination and development of integrated STEM education applications, a literature review was continuously conducted, expert opinions were taken, and revisions were made when necessary. In the first week of the experimental process, students were met, and pre-tests were carefully administered under the supervision of the researcher and a science teacher. Integrated STEM applications were applied to the experimental group sequentially or intermittently for 14 weeks. In order to prevent negative situations, two weeks have been determined as a contingency. The first and last weeks were used for data collection.

In the research context, 13 integrated STEM education applications related to the units in the first semester of the science course were used. Due to its comprehensive coverage, only two of these applications lasted for two weeks. All other applications were carried out within a week in line with the application period. Integrated STEM education practices were designed to include the achievements of the relevant units, and STEM disciplines were integrated.

The control group of the research is another 8th-grade branch in the same school. In this group, the same teacher taught the lessons following the curriculum. During the lesson, teacher-student guidebooks, student textbooks, student workbooks, and various test books were used.

Data Analysis

Since the number of students in the experimental and control groups was less than 50, normality assumptions were determined by the Shapiro-Wilks test (Büyüköztürk, 2011). Besides, skewness and kurtosis values were also considered. The single factor analysis of covariance (ANCOVA) was used in the data analysis. The relevant data provide the necessary conditions for ANCOVA.

Findings

Findings Regarding the First Sub-Problem

In line with the first sub-problem of the research, firstly, the descriptive statistics results of the post-test scores of the experimental and control groups are shown in Table 4. The mean PSIC pre-test score of the experimental group in which integrated STEM education applications were carried out is $\bar{X}$=81.72, and the post-test mean score is $\bar{X}$=88.50. In the control group, the mean PSIC pre-test score is $\bar{X}$=83.13, while the post-test mean score is $\bar{X}$=84.31. This finding can be interpreted as integrated STEM education practices are more effective on students' PS skills.

Table 4. Descriptive Statistics Results of Experimental and Control Group PSIC Pre-Test and Post-Test Scores

		N	Min	Max	$\bar{X}$	SD	Skewness	Kurtosis	S-W
Experimental Group	**Pre-test**	22	66	96	81.72	7.50	-0.359	0.652	0.17
	Post-test	22	74	109	88.50	10.13	0.288	-0.954	0.34
Control Group	**Pre-test**	22	74	90	83.18	4.06	-0.673	-0.007	0.25
	Post-test	22	76	96	84.31	5.91	0.617	-0.317	0.11

The mean PSIC pre-test score of the experimental group in which integrated STEM education applications were carried out is $\bar{X}$=81.72, while the post-test mean score is $\bar{X}$=88.50. In the control group, the mean PSIC pre-test score is $\bar{X}$=83.13, while the post-test mean score is $\bar{X}$=84.31. This finding can be interpreted as integrated STEM education practices are more effective on students' PS skills.

After controlling the necessary conditions for the analysis, ANCOVA was conducted to determine whether there was a significant relationship between the experimental and control group PSIC post-test scores. Table 5 shows the descriptive statistics of the experimental and control groups' PSIC post-test mean scores.

Table 5. Descriptive Statistics Values Based on PSIC Experimental and Control Group Post-Test Scores

Groups	**N**	$\bar{X}$	**SD**	**Adjusted Mean**
Experimental Group	22	88.50	10.13	89.01
Control Group	22	84.31	5.91	83.80

Table 5 indicates that the mean score of the PSIC post-test for the experimental group is $\bar{X}$=88.50, while it is $\bar{X}$=84.31 for the control group. This finding reflects that the post-test scores of the experimental group were higher than the post-test scores of the control group. When the pre-test scores of the groups are considered, there are differences in the post-test scores. PSIC post-test adjusted mean is $\bar{X}$=89.01 for the experimental group, while it is $\bar{X}$=83.80 for the control group. These findings show that the experimental group, in which integrated STEM education applications are carried out, improved more than the control group in terms of PS skills. However, in order to determine whether there is a statistically significant difference between the calculated values, the ANCOVA results of the post-test scores adjusted for the PSIC pre-tests are examined (Table 6).

Table 6. ANCOVA Results of Post-Test Scores Adjusted for PSIC Pre-Tests by Groups

Source of Variance	Sum of Squares	df	Sum of Squares	F	p
Model	916.484	2	473.242	9.083	0.00
Pre-Test	754.121	1	754.121	14.474	0.00
Group	293.264	1	293.264	5.629	0.00
Error	2136.152	41	52.101		
Total	331610.00	44			

Table 6 shows that there is a significant difference between the experimental and control groups' post-test mean scores adjusted for the PSIC pre-tests ($F_{(1,41)}$=5.629, p<0.05). This finding can be interpreted as the fact that the most integrated STEM education application has been effective in developing students' PS skills.

Findings Regarding the Second Sub-Problem

Within the framework of the second sub-problem of the research, it was analyzed whether there was a significant difference between the post-test scores of the experimental and control groups obtained from SCT. The descriptive statistics results of the post-test scores of the groups are shown in Table 7.

Table 7. Descriptive Statistics Results of Experimental and Control Groups' SCT Pre-Test and Post-Test Scores

		N	Min	Max	$\bar{X}$	SD	Skewness	Kurtosis	S-W
Experimental Group	**Pre-test**	22	31	66	44.40	9.57	0.692	-0.285	0.24
	Post-test	22	40	106	62.86	15.32	1.124	1.650	0.12
Control Group	**Pre-test**	22	24	54	39	9.19	0.202	-1.098	0.31
	Post-test	22	25	80	44	13.40	1.031	1.010	0.09

SCT pre-test mean score of the experimental group in which integrated STEM education applications were carried out is $\bar{X}$=44.40, while the post-test mean score is $\bar{X}$=62.86. In the control group, the pre-test mean score is $\bar{X}$=39, while the post-test mean score is $\bar{X}$=44. Considering this finding, integrated STEM education practices are more effective on students' SC.

ANCOVA was conducted to determine whether there was a significant relationship between the groups' SCT post-test scores. Table 8 shows the descriptive statistical values of the SCT post-test mean scores of the experimental and control groups that emerged because of the analysis made.

Table 8. Descriptive Statistics by SCT Experimental and Control Group Post-Test Scores

Groups	N	$\bar{X}$	SD	Adjusted Mean
Experimental Group	22	62.86	15.32	60.48
Control Group	22	44	13.40	46.38

While the SCT post-test mean scores are $\bar{X}$=62.86 for the experimental group, it is $\bar{X}$=44 for the control group. This finding indicates that the experimental group's SCT post-test scores are higher than those of the control group. When the pre-test scores of the groups are checked, changes are seen in the SCT post-test scores. SCT adjusted mean for the experimental group is $\bar{X}$=60.48, while it is $\bar{X}$=46.38 for the control group. These findings show that the experimental group, in which integrated STEM education applications were carried out, improved more than the control group in SC. However, in order to determine whether there is a statistically significant difference between the calculated values, the ANCOVA results of the post-test scores adjusted for the SCT pre-tests were examined on the basis of the groups (see Table 9).

Table 9. ANCOVA Results of Post-Test Scores Adjusted for SCT Pre-Tests by Groups

Source of Variance	**Sum of Squares**	**df**	**Sum of Squares**	**F**	**p**
Model	6784.145	2	3392.072	23.820	0.00
Pre-Test	2869.940	1	2869.940	20.153	0.00
Group	2012.139	1	2012.139	14.130	0.00
Error	5838.651	41	142.406		
Total	138241.00	44			

Table 9 reports that there is a significant difference between the post-test mean scores adjusted for the SCT pre-tests of the experimental and control groups ($F_{(1,41)}$=14.130, $p<0.05$). This finding can be interpreted as the integrated STEM education application has effectively developed students' SC.

Findings Regarding the Third Sub-Problem

Within the framework of the third sub-problem of the research, ANCOVA was conducted to determine whether the UF/EMI-CTDI post-test scores of the experimental and control groups were significant (Table 10).

Table 10. Descriptive Statistics Results of Experimental and Control Groups UF/EMI-CTDI Pre-Test and Post-Test Scores

		N	**Min**	**Max**	**$\bar{X}$**	**SD**	**Skewness**	**Kurtosis**	**S-W**
Experimental Group	**Pre-test**	22	80	100	90.54	5.81	-0.171	-0.588	0.37
	Post-test	22	86	108	98.50	6.56	-0.447	-0.704	0.18
Control Group	**Pre-test**	22	70	115	91.50	10.25	0.136	0.945	0.61
	Post-test	22	74	113	94.09	9.12	0.151	0.608	0.20

While the UF/EMI-CTDI pre-test mean scores of the experimental group in which integrated STEM education applications were carried out is $\bar{X}$=90.54, the post-test mean score is $\bar{X}$=98.50. The UF/EMI-CTDI pre-test and post-test mean scores in the control group are close. The pre-test mean score of the control group is $\bar{X}$=91.50, while the post-test mean score is $\bar{X}$=94.09. Based on these findings, integrated STEM education practices are more effective in students' CT skills.

ANCOVA was conducted to determine whether there is a significant relationship between the experimental and control groups' UF/EMI-CTDI post-test scores. Table 11 shows the descriptive statistical values of the experimental and control groups' UF/EMI-CTDI post-test mean scores.

Table 11. Descriptive Statistics According to UF/EMI-CTDI Experimental and Control Group Post-Test Scores

Groups	N	X̄	SD	Adjusted Mean
Experimental Group	22	98.50	6.56	98.72
Control Group	22	94.09	9.12	93.87

UF/EMI-CTDI post-test mean score for the experimental group is X̄=98.50, while it is X̄=94.09 for the control group. This finding shows that the UF/EMI-CTDI post-test scores of the experimental group are higher than those of the control group. While the adjusted mean of UF/EMI-CTDI is X̄=98.72 for the experimental group, it is X̄=93.87 for the control group. This finding indicates that the experimental group, in which integrated STEM education applications were carried out, improved more than the control group in terms of CT skills. However, in order to determine whether there is a statistically significant difference between the calculated values, the ANCOVA results of the post-test scores adjusted for the UF/EMI-CTDI pre-tests were examined (see Table 12).

Table 12. ANCOVA Results of Post-Test Scores Adjusted for UF/EMI-CTDI Pre-Tests by Groups

Source of Variance	Sum of Squares	df	Sum of Squares	F	p
Model	831.750	2	415.875	8.377	0.00
Pre-Test	617.909	1	617.909	12.447	0.00
Group	257.679	1	257.679	5.191	0.02
Error	2035.409	41	49.644		
Total	410871.00	44			

Table 12 suggests that there is a significant difference between the post-test mean scores adjusted for the UF/EMI-CTDI pre-tests of the experimental and control groups ($F_{(1,41)}=5.191$, $p<0.05$). This finding can be interpreted as the integrated STEM education application has been effective in students' CT skills.

Discussion and Conclusion

STEM education is a multidisciplinary contemporary approach that adopts PS skills for innovative individuals who will replace today's generation. Morrison (2006) argues that individuals raised with STEM education have the skills required by age. Besides, STEM education does not address students' problems from a single perspective, enabling them to look at them from an interdisciplinary perspective (Şahin et al., 2014). Integrated education programs formed by integrating more than one discipline enable students to develop basic skills such as PS, collaborative learning, and creative thinking (Niess, 2005).

The PSIC Post-test Scores of the Experimental Group and the Control Group

PS skills are considered one of the important skills for STEM education since integrating different disciplines to solve problems that students may encounter in daily life are among the subjects of STEM education (Williams, 2011).

The comparison of PSIC post-test scores of the experimental and control groups reports that the PSIC post-test mean score of the experimental group is significantly higher than that of the control group. This result demonstrates that integrated STEM education practices positively affect students' PS skills, which is supported by many studies with similar results in the literature (Kopcha et al., 2017; Netwong, 2018; Wade-Shepherd, 2016).

Pekbay (2017) concluded that STEM activities are effective in the development of daily life-based PS skills in his doctoral thesis with secondary school students. Similarly, Ceylan (2014) determined that STEM education in the unit of "acids and bases" affected students' PS skills. Morrison (2006) also reported that students who receive an adequate STEM education could apply their previous PS experiences to different situations. Likewise, Saleh (2016) found that STEM education develops students' PS skills.

The National Academy of Engineering (2008) emphasizes associating students' opportunities with STEM disciplines with their PS and creativity skills. Cooper and Heaverlo (2013) stated in their study that design, creativity, and PS skills are related to all disciplines of STEM education. Soros et al. (2018) indicate that students who take STEM education have higher CT and PS scores.

There are also studies in the literature that reached different results from this research (Durmuş, 2019; Elliot et al., 2001). In his study, Nağaç (2018) concluded that STEM education does not significantly affect students' PS skills. It is thought that this result is because the STEM education in the related research was carried out in a short time since the STEM applications in the experimental group of that research were carried out in 16 hours. This period is thought too short for a change in academic achievement and PS skills. However, Akerson et al. (2006) state that skills and insights that emerge quickly during a single course are difficult to maintain.

The SCT Post-test Scores of the Experimental Group and the Control Group

SC is one of the critical 21st-century skills under the theme of "Learning and Renewal Skills" (P21, 2009). It includes creative thinking components such as imagination, divergent thinking, and analogical thinking based on SC, which are prominent within the scope of "Life Skills" in the science curriculum of Turkey (Hu & Adey, 2002; MoNE, 2013).

The analysis of SCT post-test average scores adjusted for the SCT pre-test scores of the experimental and control groups exhibits that the mean of the experimental group is significantly higher than that of the control group. This result confirms that integrated STEM education application is effective in the development of students' SC, which is proved by many studies in the literature in a similar way to this result (Dazhi & Baldwin, 2020; Demir, 2021; Karakuzu, 2021; Siew & Ambo, 2020; Smyrnaiou et al., 2020).

In his research, Ugras (2018) reported that STEM education practices positively affect students' SC. Additionally, students in that study evaluated STEM education practices as fun, instructive, motivating, and creativity enhancing. Morrison (2006) expresses that individuals raised with STEM education have the skills to produce creative and innovative projects for the needs of the global world. According to Lou et al. (2017), STEM education can improve its sphere of influence by using creativity factors such as adventurousness, curiosity, imagination, and challenge.

Knezek et al. (2013) state that practice-supported projects improve students' creative tendencies in STEM fields. This result is similar to the study conducted by Erdogan et al. (2013). As a result of the experimental research carried out by Gülhan and Şahin (2016), it was observed that the SC levels of the students improved. According to Mayasari et al. (2016), products prepared with STEM education positively affect creativity. Cho and Lee (2013) concluded that the lesson plans developed on the basis of STEM and art education improve students' SC and creative personality levels. Atabaş (2020) asserted that the SC scores of the group in which STEM-based lesson plans were applied were significantly higher.

The UF/EMI CTD Scale Post-test Scores of the Experimental Group and the Control Group

Critical thinking, which includes high-level thinking processes such as analysis, creativity, and reflective thinking (Felder & Brent, 2016), is among the important 21st-century skills. The literature suggests that studies focusing on the effect of STEM education on CT skills from various aspects have increased recently (Acar, 2018; Mutakinati et al., 2018; Reynders et al., 2020; Soros et al., 2018).

When the adjusted UF/EMI-CTDI post-test scores of the experimental and control groups according to their UF/EMI-CTDI pre-test scores were compared, it was seen that the experimental group had a significantly higher mean. When the pre-test scores of the groups were analyzed, it was concluded that the average of the experimental group was higher. This result reflects that the experimental group, in which integrated STEM education applications were carried out, developed more than the control group regarding CT dispositions. Many studies in the literature show similarities with this result (Rehmat, 2015; Wosu, 2013).

As a result of her research, Acar (2018) reported that STEM education practices are effective in students' academic achievement, PS skills, and CT dispositions. Another study by Wosu (2013) confirms that STEM education has a positive effect on CT skills. Examining science teachers' opinions on STEM education, Bakırcı and Kutlu (2018) concluded that STEM education contributes to the development of high-level skills such as meaningful learning, creative thinking, and CT for students.

Elliot et al. (2001) express that integrating science and mathematics lessons positively affects students' CT skills. The results of the study by Hacıoğlu (2017) revealed that STEM-based applications improved students' CT skills as well as their SC. In another study, Capraro and Jones (2013), who highlight the impact of STEM education practices on students' 21st-century skills, assert that STEM education improves individuals' CT and PS skills.

Suggestions

Suggestions for Practice

(1) Integrated STEM education practices within the scope of the research were performed out in a one-term period. Applications can be made over a more extended time.

(2) This research used Tinkercad to draw models for integrated STEM education applications. In older age groups, this modeling software may be insufficient. Hence, other software with more advanced features is advised to be used in this sense.

Suggestions for Researchers

(1) The effects of STEM education on different education levels (elementary school, high school etc.) can be compared by detailed analysis.
(2) STEM applications for different units and curriculum objectives (mathematic curriculum, technology curriculum et al.) can be prepared, and their effects can be examined.
(3) The effects of STEM education on different variables (21st skills, learning motivation etc.) can be investigated.
(4) The impacts of STEM education applications can be examined using different (Robotic sets, LEGO, Vex Robotics and others) materials and compared with the results of this study.
(5) Since the results of the studies carried out on large groups are more generalizable, more experimental and control groups can be formed in the studies that are considered to be carried out so that they can be conducted out in a broader way.

Note

This article was produced from the first author's doctoral dissertation.

References

Acar, D. (2018). FeTeMM Eğitiminin ilkokul 4. sınıf öğrencilerinin akademik başarı, eleştirel düşünme ve problem çözme becerisi üzerine etkisi [The effect of STEM education on the academic success, critical thinking and problem solving skills of the elementary 4th grade students] (Doctoral dissertation). Gazi University, Ankara.

Admiraal, W., Post, L., Guo, P., Saab, N., Makinen, S., Rainio, O., Vuori, J., Bourgeois, J., Kortuem, G., & Danford, G. (2019). Students as Future Workers: Cross-border Multidisciplinary Learning Labs in Higher Education. International Journal of Technology in Education and Science (IJTES), 3(2), 85-94.

Akerson, V. L., Morrison, J. A., & McDuffie, A. R. (2006). One course is not enough: Preservice elementary teachers' retention of improved views of nature of science. Journal of Research in Science Teaching, 43(2), 194-213.

Akgündüz, D., Aydeniz, M., Çakmakçı, G., Çavaş, B., Çorlu, M. S., Öner, T. & Özdemir, S. (2015). STEM eğitimi Türkiye raporu [STEM education turkish report]. Scala Press.

Atabaş, Ü. (2020). STEM Eğitiminin fen bilimleri dersinde dördüncü sınıf öğrencilerinin bilimsel yaratıcılıklarına, problem çözmeye yönelik yansıtıcı düşünme becerilerine ve STEM eğitimine ilişkin görüşlerine etkisi [The effect of STEM education on fourth grade students' scientific creativity, reflective thinking skills for problem solving and opinions on Stem education in the science course] (Doctoral dissertation]). Marmara University, İstanbul.

Bağçeci, B., & Kinay, İ. (2013). Öğretmenlerin problem çözme becerilerinin bazi değişkenlere göre incelenmesi [Investigation of teachers' problem solving skills according to some variables]. Electronic Journal of Social Sciences, 12(44), 335-347.

Bakırcı, H. & Kutlu, E. (2018). Fen bilimleri öğretmenlerinin FeTeMM yaklaşımı hakkındaki görüşlerinin belirlenmesi [Determination of science teachers' views on STEM approach]. Turkish Journal of Computer and Mathematics Education (TURCOMAT), 9(2), 367-389. doi:10.16949/turkbilmat.417939

Batdi, V., Talan, T., & Semerci, C. (2019). Meta-analytic and meta-thematic analysis of STEM education. International Journal of Education in Mathematics, Science and Technology, 7(4), 382-399.

Bebek, G. (2021). Özel Yetenekli öğrencilere yönelik tasarlanan STEM etkinliğinin öğrencilerin bilimsel yaratıcılık, bilişsel başarı ve eleştirel düşünme becerisine etkisi: Yenilenebilir enerji kaynakları konusu örneği [The effect of STEM based activity designed for gifted students on students' scientific creativity, cognitive achievement and critical thinking skills: A case study on renewable energy resources] (Doctoral dissertation). Trabzon University, Trabzon.

Becker, K., & Park, K. (2011). Effect of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students learning: A preliminary meta-analysis. Journal of STEM Education, Inovations, and Research, 12(5-6),23-37.

Benek, I., & Akcay, B. (2019). Development of STEM Attitude Scale for Secondary School Students: Validity and Reliability Study. International Journal of Education in Mathematics, Science and Technology , 7(1), 32-52. doi: 10.18404/ijemst.509258

Büyüköztürk, Ş. (2011). Sosyal bilimler için veri analizi el kitabı [Manual of data analysis for social sciences]. Ankara: Pegem Academy.

Büyüköztürk, S., Kılıç Çakmak, E., Akgün, O. E., Karadeniz, Ş., & Demirel, F. (2013). Bilimsel araştırma yöntemleri [Scientific research methods]. Ankara: Pegem Academy.

Bybee, R. W. (2010). Advancing STEM Education: A 2020 vision. Technology and Engineering Teacher, 70(1), 30-35.

Bybee, R. W. (2013). The case for STEM education: Challenges and opportunities. Virginia, USA: National Science Teachers Association Press.

Capraro, M. M., & Jones, M. (2013). Interdisciplinary STEM project-based learning. In R. M. Capraro, M. M. Capraro, & J. M. Morgan (Eds.). STEM Project Based Learning (51-58) Holland: Sense Publishers.

Capraro, R. M., Capraro, M. M., Barroso, L. R., & Morgan, J. R. (2016). Through biodiversity and multiplicative principles Turkish students transform the culture of STEM education. International Journal of Education in Mathematics, Science and Technology, 4(1), 1-8.

Ceylan, S. (2014). Ortaokul fen bilimleri dersindeki asitler ve bazlar konusunda fen, teknoloji, mühendislik ve matematik (FeTeMM) yaklaşımı ile öğretim tasarımı hazırlanmasına yönelik bir çalışma [A study for preparing an instructional design based on science, technology, engineering and mathematics (STEM) approach on the topic of acids and bases at secondary school science course] (Master dissertation). Uludağ University, Bursa.

Charyton, C. (2015). Creative engineering design: The meaning of creativity and innovation in engineering. In C. Charyton (Ed.), Creativity and innovation among science and art (135-152). Germany: Springer-Verlag.

Chen, Y. L., Huang, L. F., & Wu, P. C. (2021). Preservice preschool teachers' self-efficacy in and need for STEM education professional development: STEM pedagogical belief as a mediator. Early Childhood Education Journal, 49(2), 137-147. doi:10.1007/s10643-020-01055-3

Chine, D. R., & Larwin, K. H. (2022). Using HLM to Determine a STEM programs impact on middle school academic achievement. International Journal of Research in Education and Science, 8(1), 1-17. doi: 10.46328/ijres.2607

Cho, B. & Lee, J. (2013, November). The effects of creativity and flow on learning through the STEAM education on elementary school contexts. International Conference of Educational Technology, Sejong University, South Korea.

Cooper, R., & Heaverlo, C. (2013). Problem solving and creativity and design: What influence do they have on girls' interest in STEM subject areas? American Journal of Engineering Education, 4(1), 27-38.

Corlu, M. A., Adıgüzel, T., Ayar, M. C., Çorlu, M. S., & Özel, S. (2012, Haziran). Bilim, teknoloji, mühendislik ve matematik (BTMM) eğitimi: disiplinler arası çalışmalar ve etkileşimler [Science, technology, engineering and mathematics (STEM) education: interdisciplinary studies and interactions]. X. National Science and Mathematics Education Congress, Turkey.

Çorlu, M. S. & Çallı (2017). STEM kuram ve uygulamaları [STEM theory and applications]. Ankara: Pusula Publishing.

Corlu, M. S. (2014). FeTeMM eğitimi makale çağrı mektubu [Call for Manuscripts on STEM Education]. Turkish Journal of Education, 3(1), 4-10. doi: 10.19128/turje.181071

Daugherty, M. K. (2013). The Prospect of an "A" in STEM education. Journal of STEM Education: Innovations and Research, 14(2), 10-15.

Dazhi, Y., & Baldwin, S. (2020). Using technology to support student learning in an integrated STEM learning environment. International Journal of Technology in Education, 4(1), 1-11. doi:10.46328/ijtes.v4i1.22

Demir, H. (2021). Doğada STEM etkinliklerinin 7. sınıf öğrencilerinin çevresel tutumlarına, bilimsel yaratıcılıklarına, yansıtıcı düşünme becerilerine, STEM meslek alan ilgilerine ve tutumlarına etkisi [The effect of STEM activities in nature on 7th grade students' environmental attitudes, scientific creativity, reflective thinking skills, STEM occupational interests and attitudes] (Master dissertation). Alanya Alaaddin Keykubat University, Antalya.

Doganca Kucuk, Z., Yabas, D., Boyaci, H. S., & Corlu, M. S. (2021). The impact of the earlySTEM program on teacher and student outcomes: The role of teachers' ınvolvement in the program development. International Journal of Education in Mathematics, Science, and Technology, 9(3), 371-405. doi:10.46328/ijemst.1279

Donohue, K., Buck, G.A., & Akerson, V. (2020). Where's the Science? Exploring a New Science Teacher Educator's Theoretical and Practical Understandings of Scientific Inquiry. International Journal of Research in Education and Science, 6(1), 1-13.

Dugger, W. E. (2010, December). Evolution of STEM in the United States. Paper presented at the 6th biennial international conference on technology education research, Queensland, Australia. Retrieved from: http://www.iteaconnect.org/Resources/Press Room /AustraliaPaper.pdf

Durmuş, Z. (2019). FeTeMM etkinlik merkezli laboratuvar dersinin sınıf öğretmenliği adaylarının fen öğretimine yönelik öz-yeterlik ve problem çözme becerileri üzerine etkileri [The effects of STEM activity centered laboratory course on pre-service primary school teacher on self-efficiency and problem-solving skills for science teaching] (Master dissertation). Kırşehir Ahi Evran University, Kırşehir.

Elliott, B., Oty, K., McArthur, J., & Clark, B. (2001). The effect of an interdisciplinary algebra/science course on students' problem solving skills, critical thinking skills and attitudes towards mathematics. International Journal of mathematical education in science and technology, 32(6), 811-816. doi:10.1080/00207390110053784

English, L. D. (2016). STEM education K-12: Perspectives on integration. International Journal of STEM Education, 3(1), 1-8. doi:10.1186/s40594-016-0036-1

Erdogan, N., Corlu, M. S., & Capraro, R. M. (2013). Defining innovation literacy: Do robotics programs help students develop innovation literacy skills? International Online Journal of Educational Sciences, 5(1), 1-9.

Ertaş Kılıç, H., & Şen, A. İ. (2014). UF/EMI Eleştirel düşünme eğilimi ölçeğini Türkçeye uyarlama çalışması [Turkish adaptation study of UF/EMI critical thinking disposition instrument]. Education and Science, 39(176), 1-12. doi:10.15390/EB.2014.3632

Felder, R. M., & Brent, R. (2016). Teaching and learning STEM: A practical guide. USA: Jossey-Bass.

Gülhan, F., & Şahin, F. (2016). Fen, teknoloji, mühendislik, matematik entegrasyonunun (STEM) 5. sınıf öğrencilerinin bu alanlarla ilgili algı ve tutumlarına etkisi [The effects of science-technology-engineering-math (STEM) integration on 5th grade students' perceptions and attitudes towards these areas]. International Journal of Human Sciences, 13(1), 602-620.

Guzey, S. S., Harwell, M., & Moore, T. (2014). Development of an instrument to assess attitudes toward science, technology, engineering, and mathematics (STEM). School Science and Mathematics, 114(6), 271-279.

Hacıoğlu, Y. (2017). Fen, teknoloji, mühendislik ve matematik (STEM) eğitimi temelli etkinliklerin fen bilgisi öğretmen adaylarının eleştirel ve yaratıcı düşünme becerilerine etkisi [The effect of science, technology, engineering and mathematics (STEM) education based activities on prospective science teachers' critical and creative thinking skills] (Doctoral dissertation). Gazi University, Ankara.

Hartzler, D. S. (2000). A meta-analysis of studies conducted on integrated curriculum programs and their effects on student achievement (Doctoral Dissertation) Indiana University, Indiana.

Hernandez, P. R., Bodin, R., Elliott, J. W., Ibrahim, B., Rambo-Hernandez, K. E., Chen, T. W., & de Miranda, M. A. (2014). Connecting the STEM dots: measuring the effect of an integrated engineering design intervention. International Journal of Technology and Design Education, 24(1), 107-120. doi:10.1007/s10798-013-9241-0

Herschbach, D. R. (2011). The STEM initiative: Constraints and challenges. Journal of STEM Teacher Education, 48(1), 96-122.

Howard-Brown, B., & Martinez, D. (2012, May). Engaging diverse learners through the provision of STEM education opportunities. (Policy Brief No. ED573497), SEDL, Southeast Comprehensive Centre, U. S. Department of Education. Retrieved from https://files.eric.ed.gov/fulltext/ED573497.pdf

Hu, W. & Adey, P. (2002) A scientific creativity test for secondary school students. International Journal of Science Education, 24(4), 389-404. doi:10.1080/09500690110098912

Irani, T., Rudd, R., Gallo, M., Ricketts, J., Friedel, C., & Rhoades, E. (2007). Critical Thinking Instrumentation Manual. Retrieved from http://aec.ifas.ufl.edu/abrams/step/ctmanual.pdf

Israel, M., Maynard, K., & Williamson, P. (2013). Promoting literacy-embedded, authentic STEM instruction for students with disabilities and other struggling learners. Teaching Exceptional Children, 45(4), 18-25. doi:10.1177%2F004005991304500402

Kadayıfçı, H. (2008). Yaratıcı düşünmeye dayalı öğretim modelinin öğrencilerin maddelerin ayrılması ile ilgili kavramları anlamalarına ve bilimsel yaratıcılıklarına etkisi [The effect of an instructional model based on creative thinking on students' conceptual understanding of separation of matter subject and their scientific creativity] (Doctoral dissertation). Gazi University, Ankara.

Karakuzu, B. (2021). STEM temelli Algodoo etkinliklerinin yedinci sınıf öğrencilerinin ışığın madde ile etkileşimi ünitesindeki bilimsel yaratıcılıklarına etkisi [The effect of STEM-based Algodoo activities on the scientific creativity of seventh grade students in the unit of interaction of light with matter] (Doctoral dissertation). Erciyes University, Kayseri.

Karisan, D., Macalalag, A., & Johnson, J. (2019). The effect of methods course on pre-service teachers' awareness and ıntentions of teaching science, technology, engineering, and mathematics (STEM) subjects. International Journal of Research in Education and Science, 5(1), 22-35.

Kay, K. (2010). 21st century skills: Why they matter, what they are, and how we get there. Bellanca, J. A. (Ed.). 21st century skills: Rethinking how students learn. USA: Solution Tree Press.

Kelly, J., Edgcomb, A., Bruno, J., Gordon, C., & Vahid, F. (2022). Theory to Practice: Reducing Student Attrition in Online Undergraduate Math. International Journal of Research in Education and Science (IJRES), 8(2), 187-206. Doi:10.46328/ijres.2622

Keskin, C., Akcay, H., & Kapici, H. O. (2020). The effects of environmental science e-projects on middle school students' behaviors and attitudes. International Journal of Technology in Education and Science, 4(2), 160-167.

Kim, Y. R., Park, M. S., & Tjoe, H. (2021). Discovering Concepts of Geometry through Robotics Coding Activities. International Journal of Education in Mathematics, Science, and Technology, 9(3), 406-425. https://doi.org/10.46328/ijemst.1205

Knezek, G., Christensen, R., Wood, T. T., & Periathiruvadi, S. (2013). Impact of environmental power monitoring activities on middle school student perceptions of STEM. Science Education International, 24(1), 98-123.

Kocsis, Z., Alter, E., & Pusztai, G. (2022). The Role of Student Employment in Persistence and Efficiency in STEM Higher Education. International Journal of Education in Mathematics, Science, and Technology, 10(4), 831-848. https://doi.org/10.46328/ijemst.2177

Kopcha, T. J., McGregor, J., Shin, S., Qian, Y., Choi, J., Hill, R., ... & Choi, I. (2017). Developing an integrative STEM curriculum for robotics education through educational design research. Journal of Formative Design in Learning, 1(1), 31-44. doi:10.1007/s41686-017-0005-1

Kuehnert, E., Cason, M., Young, J. & Pratt, S. (2019). A meta-analysis of reform-based professional development in STEM: Implications for effective praxis. International Journal of Technology in Education, 2(1), 60-68.

Kuenzi, J. J. (2008). Science, technology, engineering, and mathematics (STEM) education: background, federal policy, and legislative action. Congressional Research Service. Retrieved from http://digitalcommons.unl.edu/crsdocs/35/

Langdon, D., McKittrick, G., Beede, D., Khan, B. and Doms, M. (2011). STEM: Good Jobs Now and for the Future. US Department of Commerce, Economics and Statistics Administration. Retrieved from https://bit.ly/3RdafQe

Lin, K. Y., Yu, K. C., Hsiao, H. S., Chang, Y. S., & Chien, Y. H. (2020). Effects of web-based versus classroom-based STEM learning environments on the development of collaborative problem-solving skills in junior high school students. International Journal of Technology and Design Education, 30(1), 21-34. doi:10.1007/s10798-018-9488-6

Lou, S. J., Chou, Y. C., Shih, R. C., & Chung, C. C. (2017). A study of creativity in CaC2 steamship-derived STEM project-based learning. Eurasia Journal of Mathematics Science and Technology Education, 13(6), 2387-2404. doi:10.12973/eurasia.2017.01231a

Marco-Bujosa, L. (2021). Prospective Secondary Math Teachers Encountering STEM in a Methods Course: When Math is More Than "Just Math". International Journal of Technology in Education, 4(2), 247-286. doi:10.46328/ijte.41

Mayasari, T., Kadarohman, A., Rusdiana, D., & Kaniawati, I. (2016, February). Exploration of student's creativity by integrating STEM knowledge into creative products. AIP conference proceedings. AIP Publishing LLC. doi:10.1063/1.4941191

Ministry of Education (2013). İlköğretim Kurumları (İlkokullar ve Ortaokullar) Fen Bilimleri Dersi (3,4,5,6,7 ve 8. Sınıflar) Öğretim Programı [Primary Education Institutions (Primary and Secondary Schools) Science Course (3,4,5,6,7 and 8th Grades) Curriculum]. Ankara: Board of Education and Discipline.

Morrison, J. (2006). Attributes of STEM education: The student, the school, the classroom. Teaching Institute for Excellence in STEM, 20, 2-7.

Mutakinati, L., Anwari, I., & Kumano, Y. (2018). Analysis of students' critical thinking skill of middle school through STEM education project-based learning. Jurnal Pendidikan IPA Indonesia, 7(1), 54-65. doi:10.15294/jpii.v7i1.10495

Nağaç, M. (2018). 6. sınıflar fen bilimleri dersi madde ve ısı ünitesinin öğretiminde fen, teknoloji, mühendislik ve matematik (FeTeMM) eğitimi'nin öğrencilerin akademik başarısı ve problem çözme becerilerine etkisinin incelenmesi [An analysis of the effects of science, technology, engineering and mathematics (STEM) education method on the academic success and problem solving skills of 6th grade students for matter and heat unit in science course] (Master dissertation). Hatay Mustafa Kemal University, Hatay.

National Academy of Engineering (2008). Changing the conversation: Messaging for ımproving public understanding of engineering. The National Academies Press.

Netwong, T. (2018). Development of problem solving skills by integration learning following stem education for higher education. International Journal of Information and Education Technology, 8(9), 639-643. doi:10.18178/ijiet.2018.8.9.1114

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. Teaching and Teacher Education, 21(5), 509-523. doi:10.1016/j.tate.2005.03.006

NRC [National Research Council] (2009). Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics. Washington, DC: The National Academic Press.

Partnership for 21st Century Skills [P21] (2009). P21 framework definitions. Retrieved from https://bit.ly/3Aveh0K

Pekbay, C. (2017). Fen teknoloji mühendislik ve matematik etkinliklerinin ortaokul öğrencileri üzerindeki etkileri [Effects of science technology engineering and mathematics activities on middle school students] (Master dissertation). Hacettepe University, Ankara.

Preuss, M. D., Merriweather, S. P., Walton, S. D. & Butler-Purry, K. L. (2020). Minority Student Preparation for STEM PhD Study: Impact of NSF Bridge to the Doctorate Programming. International Journal of Technology in Education and Science, 4(3), 168-187.

Punzalan, C. H. (2022). STEM Interests and Future Career Perspectives of Junior High School Students: A Gender Study. International Journal of Research in Education and Science, 8(1), 93-102. doi:10.46328/ijres.2537

Raines, J. M. (2012). FirstSTEP: A preliminary review of the effects of a summer bridge program on pre-college STEM majors. Journal of STEM Education: Innovations and Research, 13(1), 22-29.

Razi, A. & Zhou, G. (2022). STEM, iSTEM, and STEAM: What is next? International Journal of Technology in Education (IJTE), 5(1), 1-29. doi: 10.46328/ijte.119

Rehmat, A. P. (2015). Engineering The path to higher-order thinking in elementary education: A problem-based learning approach for STEM integration (Doctoral Dissertation). Nevada University, Nevada.

Reynders, G., Lantz, J., Ruder, S. M., Stanford, C. L., & Cole, R. S. (2020). Rubrics to assess critical thinking and information processing in undergraduate STEM courses. International Journal of STEM Education, 7(1), 1-15. doi:s40594-020-00208-5

Ring, E. A., Dare, E. A., Crotty, E. A., & Roehrig, G. H. (2017). The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. Journal of Science Teacher Education, 28(5), 444-467.

Şahin, A., Ayar, M. C., & Adıgüzel, T. (2014). Fen, teknoloji, mühendislik ve matematik içerikli okul sonrası etkinlikler ve öğrenciler üzerindeki etkileri [STEM related after-school program activities and associated outcomes on student learning]. Educational Sciences: Theory & Practice, 14(1), 297-322.

Saleh, A. H. (2016). A proposed unit in the light of STEM approach and its effect on developing attitudes toward (STEM) and problem solving skills for primary students. International Interdisciplinary Journal of Education, 5(7), 186-217.

Sanders, M. (2009). STEM, STEM education, STEMmania. The Technology Teacher, 68(4), 20-26.

Sanders, M., & Wells, J. (2010, February). Integrative STEM Education (Paper). Virginia Department of Education Webinar, Integrative STEM/Service-Learning, Richmond, VA.

Saricam, U., & Yildirim, M. (2021). The Effects of Digital Game-based STEM Activities on Students' Interests in STEM Fields and Scientific Creativity: Minecraft Case. International Journal of Technology in Education and Science, 5(2), 166-192. doi:10.46328/ijtes.136

Serin, O., Serin, N. B., & Saygılı, G. (2010). İlköğretim düzeyindeki çocuklar için problem çözme envanteri'nin (ÇPÇE) geliştirilmesi [Developing Problem Solving Inventory for Children at the Level of Primary Education (PSIC)]. Elementery School Online, 9(2) 446-458.

Siew, N. M., & Ambo, N. (2020). The scientific creativity of fifth graders in a STEM project-based cooperative learning approach. Problems of Education in the 21st Century, 78(4), 627-643.

Smyrnaiou, Z., Georgakopoulou, E., & Sotiriou, S. (2020). Promoting a mixed-design model of scientific creativity through digital storytelling-the CCQ model for creativity. International Journal of STEM Education, 7, 25. doi:10.1186/s40594-020-00223-6

Soros, P., Ponkham, K., & Ekkapim, S. (2018, January). The results of STEM education methods for enhancing critical thinking and problem solving skill in physics the 10th grade level. AIP Conference Proceedings (Vol. 1923, No. 1, p. 030045). AIP Publishing LLC.

Talan, T. (2021). Augmented Reality in STEM Education: Bibliometric Analysis. International Journal of Technology in Education, 4(4), 605-623. doi:10.46328/ijte.136

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., ... & Depaepe, F. (2018). Integrated STEM education: A systematic review of instructional practices in secondary education. European Journal of STEM Education, 3(1), 2-12. doi:10.20897/ejsteme/85525

Turkish Industry and Business Association (2017). 2023'e doğru Türkiye'de STEM gereksinimi [STEM requirement in Turkey towards 2023]. Retrieved from https://bit.ly/3bTwxGP

Turner, I. L., Harley, M. D., Hanslow, D. J., Kinsela, M. A., & Splinter, K. D. (2022). 'Coastal Management Guide-Managing Coastal Erosion': A STEM education resource for secondary school teachers. Continental Shelf Research, 104783. doi:10.1016/j.csr.2022.104783

Ugras, M. (2018). The effect of STEM activities on STEM attitudes, scientific creavity and motivation beliefs of the students and their views on STEM education, International Online Journal of Educational Sciences, 10(5), 165-182.

Venville, G., Wallace, J., Rennie, L., & Malone, J. (2000). Bridging the boundaries of compartmentalized knowledge: Student learning in an integrated environment. Research in Science & Technological Education, 18(1), 23-35.

Wade-Shepherd, A. A. (2016). The effect of middle school STEM Curriculum on science and math achievement scores (Doctoral dissertation). Union University, Tennessee.

Wan, Z. H., Jiang, Y., & Zhan, Y. (2021). STEM education in early childhood: A review of empirical studies. Early Education and Development, 32(7), 940-962. doi:10.1080/10409289.2020.1814986

Wang, L. H., Chen, B., Hwang, G. J., Guan, J. Q., & Wang, Y. Q. (2022). Effects of digital game-based STEM education on students' learning achievement: a meta-analysis. International Journal of STEM Education, 9(1), 1-13. doi:10.1186/s40594-022-00344-0

Wannapiroon, P., Nilsook, P., Techakosit, S., & Kamkhuntod, S. (2021). STEM Literacy of Students in Vocational Education. International Journal of Technology in Education and Science, 5(4), 527-549. doi:10.46328/ijtes.253

Williams, J. (2011). STEM education: Proceed with caution. Design and Technology Education, 16(1), 26-35.

Wosu, S. N. (2013, June). Impact of academic performance improvement (API) skills on math and science achievement gains. Proceeding of American Society for Engineering Education (ASEE) Annual Conference & Exposition Washington DC, USA. American Society for Engineering Education.

Yager, R. E., & Brunkhorst, H. (2014). Exemplary STEM Programs: Designs for Success. Virginia NSTA Press, National Science Teachers Association.

Yamak, H., Bulut, N., & Dündar, S. (2014). 5. Sınıf öğrencilerinin bilimsel süreç becerileri ile fene karşı tutumlarına FeTeMM etkinliklerinin etkisi [The impact of STEM activities on 5th grade students' scientific process skills and their attitudes towards science]. Gazi University Journal of Gazi Education Faculty, 34(2), 249-265.

Yılmaz, A., Gülgün, C., & Çağlar, A. (2017). 7. Sınıf öğrencilerine "Kuvvet ve Enerji" ünitesinin STEM uygulamaları ile öğretimi: Paraşüt, su jeti, mancınık, akıllı perde ve hidrolik iş makinası (Kepçe) yapalım etkinliği [Teaching the "Force and Energy" unit to 7th grade students with STEM applications: Let's make a parachute, water jet, catapult, smart curtain and hydraulic work machine (Earth digger) activity]. Journal of Current Researches on Educational Studies, 7(1), 97-116.