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.

Key words: STEM Education, Problem Solving Skills, Scientific Creativity, Critical Thinking

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 al., 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., 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; Yilmaz et al., 2017). Many researchers recommend integrated STEM education due 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., 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).
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

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-test</th>
<th>Activities</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental Group</td>
<td>-PSIC</td>
<td>Integrated STEM Education Applications</td>
<td>-PSIC</td>
</tr>
<tr>
<td></td>
<td>-SCT</td>
<td></td>
<td>-SCT</td>
</tr>
<tr>
<td></td>
<td>-UF/EMI CTD</td>
<td></td>
<td>-UF/EMI CTD</td>
</tr>
<tr>
<td>Control Group</td>
<td>-PSIC</td>
<td>Appropriate for the Science Curriculum</td>
<td>-PSIC</td>
</tr>
<tr>
<td></td>
<td>-SCT</td>
<td></td>
<td>-SCT</td>
</tr>
<tr>
<td></td>
<td>-UF/EMI CTD</td>
<td></td>
<td>-UF/EMI CTD</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Groups</th>
<th>Female</th>
<th></th>
<th>Male</th>
<th></th>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>Experimental</td>
<td>12</td>
<td>54.5</td>
<td>10</td>
<td>45.5</td>
<td>22</td>
<td>50</td>
</tr>
<tr>
<td>Control</td>
<td>13</td>
<td>59</td>
<td>9</td>
<td>41</td>
<td>22</td>
<td>50</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>56.8</td>
<td>19</td>
<td>43.2</td>
<td>44</td>
<td>100</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Scale</th>
<th>Groups</th>
<th>N</th>
<th>X</th>
<th>SD</th>
<th>df</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSIC</td>
<td>Experimental</td>
<td>22</td>
<td>81.72</td>
<td>7.50</td>
<td>1-42</td>
<td>0.63</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>22</td>
<td>83.18</td>
<td>4.06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCT</td>
<td>Control</td>
<td>22</td>
<td>39.00</td>
<td>9.19</td>
<td>1-42</td>
<td>3.65</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>22</td>
<td>93.2</td>
<td>9.38</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UF/EMI CTD</td>
<td>Control</td>
<td>22</td>
<td>91.50</td>
<td>10.25</td>
<td>1-42</td>
<td>0.14</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>22</td>
<td>10</td>
<td>1.95</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 $\bar{X}=\text{81.72}$, and the post-test mean score is $\bar{X}=\text{88.50}$. In the control group, the mean PSIC pre-test score is $\bar{X}=\text{83.13}$, while the post-test mean score is $\bar{X}=\text{84.31}$. 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

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>$\bar{X}$</th>
<th>SD</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>S-W</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experimental Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test</td>
<td>22</td>
<td>66</td>
<td>96</td>
<td>81.72</td>
<td>7.5</td>
<td>-0.359</td>
<td>0.652</td>
<td>0.17</td>
</tr>
<tr>
<td>Post-test</td>
<td>22</td>
<td>74</td>
<td>109</td>
<td>88.50</td>
<td>10.1</td>
<td>0.288</td>
<td>-0.954</td>
<td>0.34</td>
</tr>
<tr>
<td><strong>Control Group</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test</td>
<td>22</td>
<td>74</td>
<td>90</td>
<td>83.18</td>
<td>4.06</td>
<td>-0.673</td>
<td>-0.007</td>
<td>0.25</td>
</tr>
<tr>
<td>Post-test</td>
<td>22</td>
<td>76</td>
<td>96</td>
<td>84.31</td>
<td>5.91</td>
<td>0.617</td>
<td>-0.317</td>
<td>0.11</td>
</tr>
</tbody>
</table>

The mean PSIC pre-test score of the experimental group in which integrated STEM education applications were carried out is $\bar{X}=\text{81.72}$, while the post-test mean score is $\bar{X}=\text{88.50}$. In the control group, the mean PSIC pre-test score is $\bar{X}=\text{83.13}$, while the post-test mean score is $\bar{X}=\text{84.31}$. 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

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>$\bar{X}$</th>
<th>SD</th>
<th>Adjusted Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental Group</td>
<td>22</td>
<td>88.50</td>
<td>10.13</td>
<td>89.01</td>
</tr>
<tr>
<td>Control Group</td>
<td>22</td>
<td>84.31</td>
<td>5.91</td>
<td>83.80</td>
</tr>
</tbody>
</table>

Table 5 indicates that the mean score of the PSIC post-test for the experimental group is $\bar{X}=\text{88.50}$, while it is $\bar{X}=\text{84.31}$ 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 $\bar{X}=\text{89.01}$ for the experimental group, while it is $\bar{X}=\text{83.80}$ 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

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Sum of Squares</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>916.484</td>
<td>2</td>
<td>473.242</td>
<td>9.083</td>
<td>0.00</td>
</tr>
<tr>
<td>Pre-Test</td>
<td>754.121</td>
<td>1</td>
<td>754.121</td>
<td>14.474</td>
<td>0.00</td>
</tr>
<tr>
<td>Group</td>
<td>293.264</td>
<td>1</td>
<td>293.264</td>
<td>5.629</td>
<td>0.00</td>
</tr>
<tr>
<td>Error</td>
<td>2136.152</td>
<td>41</td>
<td>52.101</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>331610.00</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>X</th>
<th>SD</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>S-W</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test</td>
<td></td>
<td>Post-test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental Group</td>
<td>22</td>
<td>31</td>
<td>66</td>
<td>44.40</td>
<td>9.57</td>
<td>-0.692</td>
<td>-0.285</td>
</tr>
<tr>
<td>Control Group</td>
<td>22</td>
<td>24</td>
<td>54</td>
<td>39</td>
<td>9.19</td>
<td>0.202</td>
<td>-1.098</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>$\bar{X}$</th>
<th>SD</th>
<th>Adjusted Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental Group</td>
<td>22</td>
<td>62.86</td>
<td>15.32</td>
<td>60.48</td>
</tr>
<tr>
<td>Control Group</td>
<td>22</td>
<td>44</td>
<td>13.40</td>
<td>46.38</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Sum of Squares</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>6784.145</td>
<td>2</td>
<td>3392.072</td>
<td>23.820</td>
<td>0.00</td>
</tr>
<tr>
<td>Pre-Test</td>
<td>2869.940</td>
<td>1</td>
<td>2869.940</td>
<td>20.153</td>
<td>0.00</td>
</tr>
<tr>
<td>Group</td>
<td>2012.139</td>
<td>1</td>
<td>2012.139</td>
<td>14.130</td>
<td>0.00</td>
</tr>
<tr>
<td>Error</td>
<td>5838.651</td>
<td>41</td>
<td>142.406</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>138241.00</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

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

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

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>X̄</th>
<th>SD</th>
<th>Adjusted Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental Group</td>
<td>22</td>
<td>98.50</td>
<td>6.56</td>
<td>98.72</td>
</tr>
<tr>
<td>Control Group</td>
<td>22</td>
<td>94.09</td>
<td>9.12</td>
<td>93.87</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Sum of Squares</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>831.750</td>
<td>2</td>
<td>415.875</td>
<td>8.377</td>
<td>0.00</td>
</tr>
<tr>
<td>Pre-Test</td>
<td>617.909</td>
<td>1</td>
<td>617.909</td>
<td>12.447</td>
<td>0.00</td>
</tr>
<tr>
<td>Group</td>
<td>257.679</td>
<td>1</td>
<td>257.679</td>
<td>5.191</td>
<td>0.02</td>
</tr>
<tr>
<td>Error</td>
<td>2035.409</td>
<td>41</td>
<td>49.644</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>410871.00</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 Effects of Integrated STEM Education Practices on Problem Solving Skills, Scientific Creativity

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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. (2016). 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, Bakirci 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.
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(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 (mathematics 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.

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