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ORIGINAL ARTICLE

The Effect of Problem-based STEM Education on the Students' Critical Thinking Tendencies and Their Perceptions for Problem Solving Skills

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ABSTRACT

This research aimed to explore the effect of problem-based STEM activities on middle school students' perceptions related to problem-solving skills and their critical thinking tendencies. The sample consisted of 81 students. A mixed method was employed in the research. The quantitative data collection tools were the "Critical Thinking Tendency Scale" and "The Perception Scale for Problem Solving Skill." The qualitative tools were a Semi-structured Interview Form and Experience diaries developed by the researcher considering the quantitative scales. While the quantitative data, obtained in the research, were analyzed with one-way ANOVA, the statistical method; and the qualitative data were analyzed with the content analysis. At the end of the research, a significant difference was detected in favor of experimental groups in the students' perceptions of their problem-solving skills and critical thinking tendencies. On the other hand, in the qualitative results, it was reported that the problem-based STEM education created a positive effect as cognitive maturity and innovativeness in the students' feelings, thought, and behaviors. It was concluded that the students used the inter-disciplinary knowledge with the problem-based STEM activities; found the problem solving, understanding the problem and working with their friends favorably. According to these results, it can be claimed that STEM education is highly effective in developing the skills that are expected from individuals in the 21st century such as problem-solving, critical thinking, and social interaction.

KEY WORDS: Critical thinking; problem-solving; STEM

INTRODUCTION

The students educated with 21st-century skills are the individuals who will help shape the future (Griffin and Care, 2014). Today's world is characterized by rapidly changing, increasing knowledge, and rivalry between countries. As a result, the expected characteristics of the individuals of the society have also changed. These characteristics are the skills such as creating solutions for real-life problems, working interdisciplinary, thinking analytically, and setting interaction (Çakır and Altun Yalçın, 2021a). Caring about the future of children, helping them, providing what is necessary, strengthening them earlier are the main purposes of education (Lillard, 2012; Çakır and Altun Yalçın, 2020). However, not only a classical education teaching only the basic concepts is needed but also the teaching methods in which students are active such as STEM education, project-based, problem-based, etc., are needed as well. Because the development of the individual's mental skills such as critical thinking and collaborative working is realized with their active participation in the learning process (Çınar et al., 2016; Çevik, 2017). Being a self-directed and productive individual necessitates having critical thinking and problem-solving skills (Semerci, 2000). Dewey defines critical thinking as the ability to support knowledge and make inferences by carefully tackling it considering certain rules (Fisher, 2001). One of the views that have gained importance in studies is also how students think rather than what they think (Kazancı, 1989). In their research, Kürüm (2002) and Şen (2009) stressed the significance of critical thinking skills in the shaping of societies. It was claimed that the students with critical thinking skills will be among those who are the successful individuals of the contemporary world in the future.

Another skill that has significance among the desired behaviors from students in the developing world is problem-solving skill (Kürüm, 2002). Problem-solving is determining the solution of an existed problem, achieving a task that requires strength, defining the problem correctly, collecting the relevant problem data, and specifying the way of a solution (Çam, 1995). Using the knowledge obtained from the previous experience is significant in finding a solution (Oğuz and Akyol, 2015). Problem-solving is a skill and this skill should be gained by the students with motivation from an early age (Bingham, 1998).

Problem-solving and critical thinking are the skills that individuals need throughout their lives (Arkan, 2011). Hence, for children to gain these skills at a young age, many countries

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have changed their curricula. One of these changes is the inclusion of STEM education (Çakır and Altun Yalçın, 2021a).

Countries have emphasized considering science, mathematics, engineering, and technology (STEM) together and focused on presenting these disciplines together (Rotherham and Willingham 2010). The concept of STEM emerged in 2001 and originated from the combination of the first letters of science, mathematics, engineering, and technology and became popular in America first and then, began to spread rapidly around the world (Altun Yalçın, 2019). Students, who have been instructed with STEM education, are educated as problem solvers, innovative, self-confident, logical thinkers, and scientifically and technologically literate (Kuenzi, 2008). STEM education is of great significance in terms of transforming theoretical knowledge into products and gaining 21st-century skills (Çınar et al., 2016). Interdisciplinary learning is achieved with STEM education. STEM education aims to educate creative leaders who have achieved economic progress, information and technology age (Akgündüz, 2017). Integrating STEM education into the national education system will enable the development of generations that are creative, productive, and equipped with 21st-century skills (Stuart and Dahm, 1999). The role of STEM education in leading countries to be developed economically is recognized with clear consensus among stakeholders (Kuenzi, 2008).

Students' experiences in science and engineering practices are of great significance to increase the scientific research and technological power, socio-economic development, and competitive strength of our country (Bal and Bedir, 2021). Students should have creative, innovative, critical thinking, problem-solving and effective decision-making skills due to the increasing economic, social, scientific, and technological developments of our age (Rotherham and Willingham, 2010). The increase in emphasizing STEM fields in education and the workforce can provide benefits in many aspects. Thus, the need for a qualified workforce in the business world can be supplied, and the opportunity to contribute to the economic development and become one of the countries that direct the future by increasing innovation and productivity with better-equipped employees (Altan, 2017). In a report published by the Association of Turkish Industrialists and Business People, the significance of STEM education was emphasized, attention was paid to the significance of STEM skills, which form the basis of innovation, in terms of economic growth (Güvenç and Altun Yalçın, 2020).

Developing the cognitive thinking and skills of the students encountering real-life problems is crucial in problem-based STEM education (Altan, 2017). Accordingly, this study aimed to explore the contribution of problem-based STEM activities to Turkish middle school students' critical thinking tendencies and perceptions for problem-solving skills. In addition, it aimed to help the students develop more disciplined and multi-directional points of view using interdisciplinary information in solving the problems that they encounter in daily life.

METHODS

Research Model

A mixed-method research design was employed. Mixed-method research studies are not a simple combination of the qualitative and quantitative methods, but integration of methods within a study where the strengths of these methods are covered by supporting research (Creswell, 2006). One of the most important features of the mixed method is that it does not limit the options of the researcher during research; broader and more comprehensive answers are obtained from the research problem (Baki and Gökçek, 2012). The combination design of the mixed method was applied in this research. The purpose of this design is to collect both the qualitative and quantitative data; combining the results of the data to analyze both and compare the results (Sözbilir, 2017) (Table 1).

Sample

The sample of the research consists of 81 students (aged 13) in the 7-C, 7-F, and 7-H classes of a secondary school in a province in Eastern Anatolia, Turkey. Among the matching types, the group matching method was used in selecting the experimental and control groups. In such matching, it is intended to provide the groups to be formed generally equivalent to each other (Büyüköztürk et al., 2014). Accordingly, the groups were determined from the different class branches (Class A and Class B) of the 7th grade, at the same class level. 7-C was selected as the control group, 7-H as the experimental Group 1, and 7-B as the experimental Group 2. The activities were performed both in the fields of science and STEM by the teacher of this course with a graduate degree. A table, presenting the number of female and male students of the classes in which the problem-based STEM practices, is given Table 2.

Implementation Process

At the beginning of the implementation, primarily a literature review related to the STEM activities for the integration of the STEM education that would be used in the research was performed. In the STEM applications, there are features that

Table 1: Symbolic representation of the research design

Groups	Pre-test	Process	Post-test
Experimental Group	T2, T3	Problem-based STEM Education (T4 was applied after each activity)	T1, T2, T3
Control Group	T2, T3	Science Practices Curriculum	T2, T3

T1: Interview form, T2: Perception scale for the problem-solving skill, T3: The Scale for Critical Thinking Tendency, T4: Experience diaries

Table 2: Research sample

Class (Group)	Gender		Total
	Male	Female	
7-C (Control Group)	12	12	24
7-F (Experimental Group-1)	11	18	29
7-H (Experimental Group-2)	11	17	28

students can use their knowledge that they will encounter problems step-by-step and they will be able to apply reason in solving problems, in which they can produce a concrete product every week in cooperation with team spirit, and develop different points of views. In implementing the problem-based STEM education, the problems selected for the students to be solved in various ways were considered.

Different STEM activities and materials were included in the course during the research process to teach in multi-disciplines, to increase their cognitive development, to raise their interests and participation in the course, and to ensure using more than one discipline in problem-solving (Table 3). Nine different activities would take 9 weeks. Before each STEM application, a problem situation was given to the students to solve. Then, at first, small groups of not more than four students were created in the experimental groups. Heterogeneity was ensured in creating the groups. Descriptive and informative activities related to the content of the activities were performed before the applications and then the applications were started. The activity that was to be performed was given to the students with the problem situation each week. The activity materials (i.e., pet bottles, straws, pet cups, CDs, strings, cardboard, and garbage skewers) were those that could easily be obtained in daily life. The materials, which were appropriate to the activity of the week, were brought according to the number of the groups. Then, the students were asked to work in groups for the activity of the week in 2 h and create unique products. In control groups, the normal education was given without grouping.

The STEM examples used in the course during the research process, the problem situations which have been created for the students to solve, and purposes and gains are follows in Table 4.

Data Collection Tool

Perception scale for the problem-solving skill: The scale, which was developed by Ekici and Balım (2013) to uncover the perceptions of the problem-solving skills of middle school students, was used. The scale is in five point Likert type with 22 items. The reliability coefficient related to the whole scale was found as 0.88.

Table 3: Problem-based STEM education application

Stage	Activity	Duration
Pre-test application	-	40+40 min
Problem situation 1:	Making a catapult	40+40 min
Problem situation 2:	Making a parachute	40+40 min
Problem situation 3:	Building a bridge	40+40 min
Problem situation 4:	Traffic light	40+40 min
Problem situation 5:	Motor car	40+40 min
Problem situation 6:	Nontipping CD	40+40 min
Problem situation 7:	Curving snake	40+40 min
Problem situation 8:	Energetic glass	40+40 min
Problem situation 9:	Money-swallowing piggy bank	40+40 min
Post-test application:	-	40+40 min

The scale for critical thinking tendency: The Critical Thinking Tendency Scale consisting of 25 items and translated into Turkish by Kılıç and Şen (2014) who applied it to 342 ninth and tenth class students, was used. The scale was, then, revised by Koçoğlu (2017) to be used on middle school students and its final version was applied in this study as the data collection tool. The reliability coefficient of the critical thinking scale was calculated as 0.91.

The qualitative data collection tools of the study consisted of the experience diaries and semi-structured interview forms. The researcher asked the participants to keep the experience diaries to evaluate the process. Experience diaries were the written and registered reports of teaching experiences. The students were told that it was necessary to write their diaries after the application of the problem-based STEM activities. Besides, the semi-structured interview form was prepared by the researcher by considering the quantitative scale items measuring the perception for problem-solving skills and critical thinking tendencies and consisted of two open-ended questions specified by consulting three experts in the field of education:

> Question 1: How do you behave when you encounter a problem? How do you feel when you face a problem? Why?
> Question 2: What do you do when you encounter a new idea or information? What do you think about reaching the correct information? Do you take the others' opinions into account?

Analysis of the Data

It was decided to apply the One-way ANOVA in calculating the significance of the difference between the independent means during the research process as there are three groups. As a result of this test, a significant difference occurred in favor of experimental Group 1 and experimental Group 2. A significant difference occurred between the groups and the *post hoc* test was used to determine the group from which this difference originated (Köklü et al., 2006). It was determined that the students had not taken any education related to STEM before as the teacher had been with them for many years. Therefore, it was thought that the only significant difference that emerged with the *post hoc* test during the process of this research originated from the education process provided to them.

The content analysis method was used in the analysis of the qualitative data. Cohen et al. (2007) defined content analysis as a technique that provides the classification of the collected texts, comparing them, and arranging the results obtained from the data. In this study, the answers were classified with codes appropriate to the content analysis first. Then, similar codes were grouped under the same categories. Finally, the codes and categories were interpreted by tabularizing.

Findings

The quantitative and qualitative findings obtained in the research are presented in Table 5.

For the perception for the problem solving skill pre-test ($F(2.78) = 0.491$; $\rho = 0.614 > 0.05$), Critical Thinking Tendency

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Table 4: The problem situations in STEM activities, purposes, and gains

Activity Name	Given Problem	Purpose	Gains
Making a catapult	Designing a catapult that can throw the given object the farthest with the cheapest materials.	The activity aims at students' problem-solving skills, teamwork, and creativity necessary for the design.	Develops problem-solving, critical thinking skills. Develop teamwork and cooperation. Participates in the engineering design process. Explains the conversion of kinetic and potential energy types into each other with examples.
Making a parachute	Make a design that will enable the egg given to you to reach the ground when fell from a higher window without breaking it.	They try to make a parachute by considering the maximum factors not to break the egg.	Makes observations and experiments. Develops teamwork and cooperation. Participates in the engineering design process. Develops problem-solving skills.
Building a bridge	The strongest bridge, with the length and width given, only with potatoes and skewers, will be built.	How can I build a stronger bridge?	Makes experiments and observations by using the scientific method. Participates in and discusses the engineering design process. Performs teamwork with group members. Comprehends the significance of geometry in daily life.
Let's make a traffic light	How can you make a traffic light with a fruit juice can?	Designing a traffic light by using the conductivity of the can.	Develops problem-solving skills. Teamwork and communication. Participates in the engineering design process. Designs a model. Makes experiments on the conversion of electrical energy into heat and light energy and observes the result.
Making a car	Design the fastest car by using limited materials.	Will compare, compete for the designs that s/he makes with group members with the activities of other groups, realize active learning by making experiments and observation.	Designs for the conversion of electrical energy into motion energy. Explains the principles under the design. Gains problem-solving skills. Comprehends that friction force has a facilitating effect.
Making nontipping CD	How can I hold the CD stable without tipping over?	Aims to solve that vibration has a mechanical effect around the equilibrium point. Sets a motor and a simple electrical circuit to vibrate the CD.	Comprehends that electrical energy can be transformed into motion energy. Participates in the engineering design process. Develops problem-solving skills. Develops critical thinking skills.
Making a curving snake	How can I make a moving snake by using a simple electrical circuit and friction?	They will make a design that will reduce the friction force and move easily with the materials given.	Compares biomimetic science with the study of nature. Participates in the engineering design process. Develops creativity, problem-solving skills. Discovers simple laws of nature.
Making an energetic glass	How can a glass move?	The students think about how they can store more energy in the glass by using any tyre. They learn the effect of friction force on motion by making observations and experiments.	Participates in the engineering design process. Comprehends the effect of friction force on the motion. Develops problem-solving skills. Comprehends the relationship between science and technology. Explains the scientific principles lying under the model.
Making a money-swallowing piggy bank	The students were asked to make the piggy bank that resembles a living thing by doing a biomimetic study. They were asked to make hands and arms and a hand taking the coin to the mouth of the piggy bank.	The students tried to make a scientific analysis of the behavior by making good observations in biomimetic studies. They will learn through entertainment that the command behavior that will make the hand move comes from the brain.	Comprehends the scientific principles lying under the model. Develops problem-solving skills. Develops teamwork and communication skills.

pre-test was ($F(2.78) = 1.67$; $\rho = 0.195 > 0.05$), the perception for the problem solving skill post-test was ($F(2.78) = 1.255$; $\rho = 0.291 > 0.05$), and critical thinking tendency post-test was ($F(2.78) = 1.882$; $\rho = 0.159$); the Levene test results applied for the homogeneity of the variances demonstrated normal distribution.

Data Obtained According to the Pre-test Results

One-way ANOVA test was used to determine whether there was a difference related to the students' problem-solving skills and the perceptions for their critical thinking tendencies and the results are presented in Tables 6 and 7.

When Table 6 is analyzed, there was a statistically significant difference between the pre-test group variable data (F = 1.026; ρ = 0.363) related to the students' perceptions of their problem-solving skills. Considering these data and findings, it can be stated that there was a balance between the control and experimental groups in terms of problem-solving perception.

As Table 7 is analyzed, it is observed that there was no statistical difference between the pre-test data (F = 1.369; ρ = 0.260) related to the students' critical thinking tendencies. When the findings are taken into consideration, it can be claimed that the control and experimental groups were equal in terms of critical thinking disposition before starting the application study.

Data Obtained According to the Post-test Results

In Table 8, the students' perceptions related to their problem-solving skills are analyzed, it is observed that there was a statistically significant difference between the post-test data (F = 28,350; ρ = 0.000) between the groups. In the variances homogeneous analysis among the *post hoc* tests applied to determine the group to which there is a significant difference in favor of, it was determined that there was a significant difference in favor of the experimental Group 1, between the experimental Group 1 and control group; a significant difference emerges in favor of the experimental Group 2, between the experimental Group 2 and control group; no significant difference between experimental Group 1 and experimental Group 2. Considering these results, it was determined that the problem-based STEM activities contributed positively to the students' problem-solving skill perceptions. The differences between the groups are summarized in Table 9.

Table 10 presents the students' opinions related to their critical thinking tendencies. It is observed that there was a statistically significant difference between the post-test data (F = 43.707; ρ < 0.001) between the groups. In the LSD analysis among the *post hoc* tests applied to determine the group to which there was a significant difference in favor of, it was determined that there was a significant difference in favor of the experimental Group 1 between the experimental Group 1 and the control group; a significant difference in favor of experimental Group 2 between the experimental Group 2 and control group; and no significant difference between the experimental Group 1 and the experimental Group 2. Considering these results, it can be argued that problem-based STEM activities develop the students' critical thinking tendency skills.

Table 5: Descriptive results indicating the homogeneity of problem-solving and critical thinking interscale variances

Measurements	Levene Statistic	Df1	Df2	Sig.
Problem-solving perception pre-	0.491	2	78	0.614
Critical thinking pre-	1.670	2	78	0.195
Problem-solving perception post	1.255	2	78	0.291
Critical thinking post	2.994	2	78	0.056

Table 6: One-way ANOVA test related to the student's problem-solving skills before the application

Groups	n	X	ss	F	ρ
Control	24	2.9625	0.43119	1.026	0.363
Experimental 1	29	2.8172	0.32301		
Experimental 2	28	2.8893	0.35312		
Total	81	2.8852	0.36814		

Table 7: The one-way ANOVA test related to the students' critical thinking tendency before the application

Groups	n	X	ss	F	ρ
Control	24	3.2917	0.29180	1.369	0.260
Experimental 1	29	3.1034	0.51926		
Experimental 2	28	3.2464	0.45091		
Total	81	3.2086	0.44051		

Table 8: The one-way ANOVA test related to the students' problem-solving skills after the application

Groups	n	X	ss	F	ρ
Control	24	3.0750	0.06027	28.350	0.000
Experimental 1	29	3.6241	0.22465		
Experimental 2	28	3.6000	0.34960		
Total	81	3.4531	0.38082		

Table 9: Between control and experiment groups significant difference table in LSD analysis from *post hoc* relationship

Groups	Control	Experimental 1	Experimental 2
Control	No difference	Difference	Difference
Experimental 1			No difference
Experimental 2		No difference	

Table 10: The one-way ANOVA test results related to the students' critical thinking tendencies after the application

Group	n	X	ss	F	ρ
Control	24	3.3875	0.04975	43.707	0.000
Experimental 1	29	4.0724	0.07985		
Experimental 2	28	4.2429	0.06008		
Total	81	3.9284	0.05509		

Findings Related to the Qualitative Data

The qualitative data obtained from the semi-structured interview form and experience diaries were analyzed with content analysis. By making necessary evaluations, the students' answers to the questions were analyzed, the codes

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and themes in the answers, the frequency values related to the themes were calculated.

Three categories are created in Table 11 considering the answers given by the students who participated in the research as the experimental group to the questions "how do you behave when you faced with a problem? How do you feel when you are faced with a problem?" In the category of understanding the problem, the students claimed that they could now explore the problems they faced in all aspects, do research for solutions and learn to understand the problem thanks to the problem-based STEM applications. In the category of solution of the problem, the students claimed that they tried different ways to reach the results after they understood the problem. In the category of giving up the solution, two students claimed that they would not try much to solve the problem they faced, postpone, and give up the solution.

In Table 12, three categories were created from the answers of the experimental group students who participated in the study to the questions "What do you do when you encounter a new idea and information? What do you think about reaching the correct information? Do you take the others' opinions into account?" In the category of cognitive-social development, the students claimed that they learned to be open and respectful to others' new and different opinions, care about different ideas, can make evaluations, struggle to reach the result with the problem-based STEM applications. In the category of participation, the students claimed that they started to love doing research and learning, to have the ability to generate different alternative ideas, that they began to interest in different issues related to STEM, that their beliefs in reaching logical conclusions increased and that they were happy with what they learned. In the category of innovativeness, they stated that they learned to try different ways to solve the problem, and they evaluated different opinions with an innovative perspective.

As Table 13 is analyzed, the students' answers related to the experience diaries of the Problem-Based STEM activities which were held every week are included. In these codes, the students expressed that they found the activities related to the applications as very interesting and entertaining, that they wanted the STEM activities to be applied in all courses, that their belief related to creating solutions against the problems given during the activity, that they learned to create different ways of solution, that they created new ideas and enjoyed cooperative working. In addition, they claimed that they enjoyed the competitions which were held in the activities, became happy when they achieved and completed their missing knowledge.

Table 11: Student opinions on question 1

Categories	Codes	f
Understanding the problem	Problem	13
	Analyzing	13
	Reaching the solution	6
	Searching	6
Solution of the problem	Different ways	17
Giving up the solution	Surrender	1
	Postponing	1

Table 12: Student opinions on question 2

Categories	Codes	f
Cognitive-social development	Different-new idea	9
	Being respectful	3
	Caring	5
	Stating obviously	9
	Struggling	3
	Evaluation	3
Participation	Reasonable result	5
	Being sure	5
	Be interested	6
	Different learning	3
Innovativeness	Being open to new ideas	2
	Solution ways	2
	Different view	3

Table 13: The experience diary views of the experimental group students

STEM applications	Codes in students' answers	f
Making a catapult	STEM activities	29
	Entertaining	31
	Problem-solving	27
Making a parachute	Finding it interesting	29
	STEM activities	38
	Entertaining competition	40
	Problem-solving	27
Building a bridge	To achieve	9
	To be happy	9
	Completing deficiencies	9
	Problem-solving	9
Making a traffic light	Entertaining competition	25
	Problem-solving	36
	Significant activity	43
	STEM activities	43
Making a motor car	Problem-solving	36
	Different ways of solution	20
	Solidarity	23
Making a nontipping CD	Problem-solving	69
	STEM activities	43
	Entertaining competition	40
	Solidarity	40
Making a curving snake	Solving the problem	32
	Believe	24
	STEM activity	38
Making an energetic glass	Very interesting	35
	Cooperation	
	STEM is entertaining	
Making a money-swallowing piggy bank	Enjoying	42
	Problem-solving	38

Some of the examples of the students' answers related to the experience diaries are presented below:

.I wish I had had all the courses through STEM activities.

.I enjoyed much, I never thought that I wouldn't solve the problem given.

...I am happy since I achieved, I completed my deficiencies.

...I learned to create different solutions to the problem.

...I enjoyed cooperation.

...I find it appropriate to use STEM activities in lessons.

...It was interesting. I worked collaboratively.

RESULTS AND DISCUSSION

It was concluded that a significant difference was found in favor of the experiment group in the post-test in the perception scores related to the students' problem-solving skills between the experimental group, in which the problem-based STEM activities were held, and the control group in which the course was implemented according to the normal curriculum of the science practices. These findings indicated that the STEM practices created a positive effect on the students' perceptions related to their problem-solving skills. Supporting the results, in the study carried out with 172 students by Lee et al. (2013), it was found that STEM education increased students' problem-solving interests. Kim and Hong (2014) concluded that STEM education increased students' problem-solving skills and abilities. Similarly, Lou et al. (2014) claimed that applying the STEM information in the solution of difficulties and analysis of problems increased students' knowledge and provided deeper solutions. Thurmond (2011), in a study conducted to get richer data in the course, concluded that problem-solving skills increased with STEM education. Lou et al. (2011) argued that STEM education broadened students' knowledge through problem-solving and strengthened their learning by discussing with their friends. Acar et al. (2020) explored the relationship between the achievement of the students, who got the STEM education, in science and mathematics and their ability to solve non-routine problems in the same fields. They claimed that both mathematics and problem-solving skills of the students, who got trained with STEM education, increased. Öner and Yılmaz (2019) investigated the relationship between the secondary school students' problem solving and inquiry learning skills perceptions and their perceptions and attitudes towards STEM. The results indicated that there was a positive significant relationship between the students' perceptions related to their problem-solving skills and their attitude toward STEM. Kurtuluş (2019) explored the effect of the STEM-based Lego activities on the secondary school 6th graders' problem-solving skills, STEM attitudes, their motivations toward science learning, and their academic achievements.

In the present research, it was found that the students' motivations toward science learning increased, they developed their problem-solving skills and increased their academic achievements. A significant difference was found in favor of the experiment group in the post-test in the critical thinking tendency scores of the students between the experimental group, in which the problem-based STEM activities were held, and the control group in which the course was implemented according to the normal curriculum of the science practices. These findings indicated that the STEM applications have a positive effect on the students' critical thinking tendencies. Supporting the results, Patrick (1986) claimed that the students can easily express their ideas in the classroom environments where the critical thinking environment is created. Rehmat (2015) found that critical thinking skills can be increased with STEM education. In another relevant study, Morrison (2006) referred that it enabled critical thinking among the benefits of STEM education. Özçelik and Akgündüz (2018) concluded that the STEM education for the gifted/talented students provided 21st-century skills such as creativity, critical thinking, cooperation, and communication with the science and mathematics achievements to them. Kurtuluş (2019) investigated the effect of STEM-based Lego activities on the 6th graders' problem-solving skills, STEM attitudes, motivations toward science learning, and academic achievement. In conclusion, it was determined that the students increased their motivations towards science learning, developed their problem-solving skills, and increased their academic achievements.

Considering the interviews, the students expressed answers stating that when students encountered a problem, they examined all aspects of the problem, researched to reach a solution, tried different solutions, respected and cared about other ideas, strived to reach the truth, were happy to learn and open to new ideas, and their self-confidence increased. Considering these results, it is understood that the STEM applications increased the students' critical thinking tendencies and problem-solving skills. In the result of the research by Dirimeşe (2006), it was found that the nursing school students, who were educated with the problem-based learning model, had more critical thinking tendencies. In the STEM education report prepared by Akgündüz (2015), it is stated the most significant movement among the 21st-century achievements is taking the initiative in problem-solving. STEM education focuses on problem-solving from an interdisciplinary perspective (Şahin et al., 2014). Dischino et al. (2011) claimed that problem-based learning and STEM education develop students in terms of problem-solving and it is among the skills that are crucial for achievement in the 21st century. In the answers to the interview questions, the students stated that they tried to understand the problem at first; then, they focused on the solution of the problem. On the other hand, two students expressed negative opinions on this topic as they did not want to solve the problem. Corbett and Coriell (2014) stated the significance of the stages such as defining the problem, determining the significance of the problem and brainstorming related to the solution in the STEM education process. In

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addition, Özcan and Koca (2019) stated in their study results of the STEM education with the 7th graders that the students found the course entertaining, affected acquiring information positively, increased the achievement, self-confidence, and socialization skills.

In the results obtained with the experience diaries, it was noticed that the students had more difficulty during the stages of being aware of the problem and solving the problem while solving the problem with the problem-based STEM applications. They claimed that they benefitted from different disciplines thanks to the problem-based STEM application. Ercan (2014) listed that it is essential to associate with each other instead of using the disciplines differently in STEM activities. Tarkın and Günbatar (2017) argue that individuals who were trained in STEM activities would be more successful in providing interdisciplinary relationships. The students mentioned their interactions with their friends while solving problems in their experience diaries and they stated that the STEM practice with the group was more positive. The students stated in the experience diaries that it might be difficult to solve the problem individually and that they solved the problems more easily by exchanging ideas with their friends. The result of the study conducted by Şahin et al. (2014) indicated that with STEM applications, students’ skills of working in a group increase positively, allowing them to notice different ideas in problem-solving and to reach a solution. Bicer et al. (2015) stated in their PBL STEM studies that the students shared the solutions of the problems with their peers, a significant feature of STEM PBL; and thus, strengthened their communication skills using context-specific terms. Besides, in the experience diaries, the students referred that they continually worked on solving the problem and looked for new ways to solve these problems. It can be stated that this situation developed their problem-solving skills. Anyoha (2017) argues that the individuals who constantly solve problems become more skilled in problem-solving. They have more practical behaviors and thinking skills in solving the problems that they encounter by enabling different mental functions to work while solving problems. In the experience diary, it was found that some students thought that their interest in the fields of science increased and wanted to be engineers. Considering these students’ opinions, it was concluded that the problem-based STEM applications about the profession that students will choose in the future affect their choice of profession. Özçelik and Akgündüz (2018) referred that the students’ tendencies related to the STEM fields in selecting profession increased with the STEM applications. As a result of the project-based STEM education by Çevik (2017), it was found that it had a positive contribution to their job selection. Similarly, Aydın et al. (2017) argued that the students who performed the STEM applications wanted to choose the STEM profession fields such as veterinary, medicine, nursing, and engineering which science and mathematics courses are more related.

One of the most significant problems today is that children expect the solution of every problem they face, directly from their teachers, parents or their environment, and do not make an effort to find a solution. These individuals are asked to create solutions related to the problems that they may come across in daily life by using their experiences that had from their former life skills. Using the knowledge obtained from the previous experiences in problem-solving is significant. Therefore, implementing the problem-based activities to the students helps them to use the ways of solution that they have learned from their previous knowledge and experiences. Problem-solving is a skill that individuals will need all through their lives. In addition, choosing and making a decision are the most crucial concepts for students in the problem-based learning process.

Students both take responsibility and gain mental autonomy by making choices by working with their group mates. Another significant opinion that has gained significance in the conducted studies is the critical thinking skill that helps with problem-solving and is based on “how” students think rather than “what” they think. The purpose here is to educate the individuals who know how to get information, construct knowledge by asking internal questions to themselves, be aware of their thinking process and have different points of view. Hence, the individuals who gain these skills will be more positive toward life, more willing to solve problems, more prone to producing solutions, more self-confident and highly motivated, productive individuals. This will enable us to train creative individuals who are required and needed in our century, can think scientifically, solve the problem, work interdisciplinary, set cooperation. Accordingly, it was tried to explore the effect of problem-based STEM education on the problem solving and critical thinking skills of the secondary school students in this study.

CONCLUSION

Problem-solving is a skill that individuals need throughout their lives (Bingham, 1998). Acquiring this skill from the pre-school period, when learning is most active, through motivation will be useful (Arkan, 2011). Thus, the child can create ways of the solution against different problem situations willingly, gain different problem situations, self-confidence, self-directed learning skills, such as effective time management, using their own experiences, and self-learning. Problem-solving does not only contribute a mental skill to the individual but also enables behaviors such as competing against the constantly developing world in the 21st century, producing and keeping up with innovations. In addition, problem-solving enables the individual to look at the solution with a critical point of view using the existing knowledge (Aslan and Sağır, 2011; Çakır and Altun Yalçın, 2021b; Oğuz and Akyol, 2015). Critical thinking skill, which is as significant as problem-solving, provides the child with characteristics such as being curious, self-confident, analytical, truth-seeking, open-minded, systematic, and intellectual maturity (Branch, 2000). Some researchers such as Şengül and Üstündağ (2009), Korkmaz (2009) and Torun (2011) claimed in their research that the critical thinking levels of individuals were not sufficient level. Considering

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this deficiency in the literature, some recommendations can be given according to the results of this study. These can be listed as follows. It is thought that implementing the activities related to these skills in the pre-school period and in different courses, which have a critical period in the acquisition of these skills, will give more beneficial results. According to the experience diaries in the research process, positive results will be reached in increasing the interest in STEM professions by contributing to the orientation of students in their job preferences and by starting this education in lower classes. Besides, as it has been found that the STEM applications develop cooperation and group work, it is thought that students will have better communication skills in terms of interpersonal harmony and cooperation at a very young age, with the integration of problem-based STEM practices into pre-school education.

Ethical Statement

This is a study with permission from the Human Research Ethics Committee of Erzincan Binali Yıldırım University with protocol number 09/11 on November 30, 2017. The voluntary individuals selected from the sample were informed about the topic by signing the consent form in the research. Nothing was done related to the Scientific Research and Publication Ethics, and all the rules in the Higher Education Institutions Scientific Research and Publication Ethics Directive were taken into consideration.

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