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### The Influence of Project-Based STEM (PjBL-STEM) Applications on the Development of 21st-Century Skills

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#### ABSTRACT

This study aimed to investigate the influence of Project-Based Learning STEM (PjBL-STEM) Applications involving the use of waste materials on the 21st-century skills of 10th-grade students. In line with the purpose of the study, the pre-experimental design was used. The sample consisted of 24 students in total. The 21st-Century Skills Usage Scale, structured and semi-structured interview forms, were used as the data collection tools. During the applications, PjBL-STEM activities were carried out. The data collected were analyzed using the Wilcoxon Signed Ranks Test and the thematic analysis technique. The data analysis revealed a significant increase in the students' 21st-century skills, such as their levels of use of autonomy and cooperation skills and their levels of environmental sensitiveness. The students also reported that the activities had positive effects on many of their 21st-century skills such as communication, and collaboration, problem-solving, creativity, critical thinking, responsibility, environmental awareness, and information-technology literacy. Based on the findings, the following suggestions were put forward: PjBL-STEM activities could be carried out more in educational institutions belonging to the Ministry of National Education. Teacher-training activities could be carried out, and in-service training could be organized to support the application of innovative methods.

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#### Introduction

Globalization is a process of economic, social, and cultural exchange throughout the world. Globalization not only helps serve commercial purposes but also contributes to the field of education. Technological developments and the knowledge economy redirected the globalization process in education, and globalization has gained a techno-economic aspect. As the result of the technological developments, the fourth industrial development, which is called Industry 4.0, focuses on the digitalization of information, such as robotics, artificial intelligence, 3D printings, nanotechnology, biotechnology, the internet of things, etc. (Schwab, 2016; Sudibjo et al., 2019). Following that, Society 5.0, a super-smart society, risen as the development of Industry 4.0. Society 5.0 prioritizes a human-centered society that integrates physical and cyberspace to solve social problems, such as sustainable issues, global warming, inexpensive and clean energy, community participation, economic disruption,

etc. The main idea of Society 5.0 is to create a comfortable world and to improve economic growth and social welfare for humanity (Fukuda, 2020). So that knowledge-based production has become a distinctive characteristic of global economies (Carrillo, 2015). The development of Society 5.0 and Industry 4.0 that are also based on a knowledge-based economy via the development of skills, or via the development of the human capital, has become an important agenda in the education policies of a number of countries (Bates, 2002).

Consequently, due to high demands in technological and scientific skills in today's society, rather than muscular or physical strength, there is now a need for well-educated individuals with the STEM workforce (science, technology, engineering, and mathematics). This change has brought about a compulsory change in the requirements of the current era. Today, in the age of Industry 4.0 and Society 5.0, there is a need for people who can engage in technological development and use multiple skills to contribute to society's development. Hence in Society 5.0, having a job requires such 21st-century skills as critical thinking, problem-solving, teamwork, good use of technology, interdisciplinary working, establishing communication, and creativity. Therefore, countries rely on individuals with STEM skills to incorporate industries and governmental institutions to get involved in the global economy (National Academies of Sciences, Engineering, and Medicine [NASEM], 2016). Thus today, investment in the STEM workforce increasingly takes place among countries' goals (Aydeniz, 2017). One reason for this increase is that in the 21st-century, employers' or manufacturers' demands are parallel to STEM skills. Because of that, there's a shift in countries' education systems to raise individuals who have 21st-century skills.

## **STEM Approach**

STEM education reminds of several concepts such as 21st-century skills, global economy, knowledge economy, industry 4.0, and society 5.0 because STEM education is considered to have an important place in training the qualified manpower thanks to the necessary knowledge and skills that provide global competition in the economy (Corlu et al, 2014; TÜSİAD, 2017).

STEM education is a method of teaching and learning which covers the skills in science, technology, engineering, and mathematics, which supports interdisciplinary education and addresses all the formal and informal educational levels from preschool education to postdoctoral education (Gonzalez & Kuenzi, 2012). When the related literature is reviewed, it is seen that STEM education increases students' success (Yıldırım & Altun, 2015) and interests (Şahin et al., 2014; Gülhan & Şahin, 2016) in STEM fields and that STEM education develops the 21st-century skills (Şahin et al., 2014) such as problem-solving (Çavaş et al., 2013; Suratno et al., 2020), critical thinking (Rogers & Portsmore, 2004), and the process skills of creativity (Parmin & Sajidan, 2019), observation and doing experiments (Strong, 2013).

In the 21st-century, STEM has influenced the agenda in Turkey as well as the agenda in the world. This influence is observed not only in the field of education but also in the agenda of a number of industrial and commercial institutions including TÜSİAD (2017).

## **STEM and Project-Based Learning**

STEM has been integrated into numerous constructive methods such as problem-based learning (LaForce et al., 2017), inquiry-based learning (Levin & Tsybulsky, 2017), cooperative learning (Aslan-Tutak et al., 2017), and project-based learning (Capraro & Slough, 2013, p.1). Because the method of Project-based Learning (PjBL) involves project production and practice-oriented learning and because these activities meet the "engineering" skills in STEM education, these two approaches are actually similar (Slough & Milam, 2013, p.15). For this reason, project-based learning is regarded as one of the most appropriate methods for the development of STEM skills (Çevik, 2018; Khairani, 2017; Şahin, 2015; Turner, 2018). PjBL-STEM is a method of teaching and learning which implies STEM

education which is based on the inclusion of STEM education in the Pjbl curriculum design (Lou et al., 2017).

Project-based learning, which appeared as a result of Dewey's emphasis on the importance of applied teaching, has been discussed in the field of education for longer than a century and applied in educational institutions since the 1990s (Thomas, 2000). Pjbl is a method of teaching which requires students to do research in groups in a certain period with the help of real-life, complex, and hard-to-solve problems (LaForce et al., 2017; Turner, 2018). Pjbl is an approach that allows students to structure their knowledge in a scientific manner thanks to teamwork and problem solving (Krajcik et al., 1999).

In literature, it is reported that the Pjbl method mostly increases students' success (Barak & Dori, 2003; Chua, 2014; ) and has a positive influence on students' participation (Brush & Saye, 2008), their motivation in lessons (De Graaf & Kolmos, 2015), their attitudes towards the course (Hernandez-Ramos & Paz, 2009), interests and on such cognitive and transferrable 21st-century skills as critical thinking skills (Zoller, 1991), establishing communication, problem-solving and teamwork (Hamurcu, 2000).

### **Influence of Pjbl-STEM Activities on the Development of 21st-Century Skills**

As mentioned before, in line with globalization, Industry 4.0, and Society 5.0, the qualifications that 21st-century individuals are expected to own differed naturally. In the literature on 21st-century skills, there is no single definition. However, as a result of related studies, several 21st-century skills have been determined based on the qualifications that manufacturers or employers require their future employees to have (Şahin, 2015). These qualifications include a number of skills as follows: coming to work punctually, paying attention to business ethics, thinking critically, working in a team, having ethical values, having information technology and problem-solving skills, making good use of communication skills, global awareness, creativity, embracing other cultures and making decisions (Casner-Lotto & Barrington, 2006; National Research Council (NRC), 2012). Thanks to 21st-century skills, students can direct their knowledge to different disciplines such as real-life contexts or socio-scientific issues in the process of finding solutions. Moreover, with the help of appropriate technologies, 21st-century skills make learning more meaningful and allow individuals to regard science as a part of their own lives. In relation to these skills, the most common 21st-century skills are "Partnership for 21st-Century Learning (P21) / 21st-Century Skills Framework in Curriculum and Teaching". In these frameworks, learning and innovation refer to being prepared for business environments, learning the increasingly complicated life, and developing innovation. Information, media, and technology skills are those which individuals are supposed to have in line with the rapidly developing technologies in such fields as information literacy and media literacy. Life and career skills refer to demonstrating certain behaviors to be successful both in life and in the business world. Harmony between individuals, social skills, taking risks, and undertaking responsibilities are examples of these 21st-century skills (Partnership for 21st-Century Skills, 2015 cited in Cansoy, 2018). 21st-century skills are those which individuals will use throughout their lives and which will contribute to their personal development and their relations with the world. Therefore, it is important to provide the materials, activities, and sources which will help develop individuals' 21st-century skills in formal or informal educational environments (LaForce et al., 2017).

As an innovative method, project-based learning is a constructive method of learning which develops individuals' skills such as producing projects, presenting the information or data systematically, establishing communication, and working in a team so that they can not only learn by doing research but also produce solutions to real-life contexts or socio-scientific subjects (Mergendoller et al., 2006) which is also important for Society 5.0. On the other hand, STEM education gathers four disciplines and aims to develop various 21st-century skills of students in the fields of science, technology, engineering, and mathematics.

In literature, it is reported that the integration of these two approaches and their adaptation to the curriculum naturally develop the 21st-century skills of students (Bell, 2010; Şahin, 2015, p.174; Netwong, 2018). For example, Şahin (2015) determined the views of 120 11th grade students and found that the Pjbl-STEM education had a positive influence on the participants' levels of patience and creativity as well as on their communication and cooperation/group work skills, critical thinking, communication, leadership, and problem-solving skills. Conducted research with 60 9th grade students by Lou et al. (2017) reported that the Pjbl-STEM education had a positive influence not only on group work and problem-solving skills of the participants but also on their creativity. Netwong (2018) carried out a study with 33 university students and found that STEM education had a positive influence on the students' problem-solving skills as well as on such skills as communication, cooperation, information technology, leadership, self-management, and responsibility. Another study conducted by Cooper and Heaverlo (2013) with 915 secondary school and high school female students revealed that the creativity and problem-solving skills of the participants were influenced positively by STEM education.

It was also found that motivating students with interdisciplinary authentic problems, the Pjbl-STEM method helps students solve real-life problems by developing and making use of their cooperative problem-solving skills (Hickey, 2014), increases their senses of responsibility (Connors-Kellgren et al., 2016), allows them to solve the problems from the perspectives of a scientist or an engineer (Capraro & Slough, 2013, p.1-2) and thus develops their scientific process skills indirectly (Satchwell & Loepp, 2002). Furthermore, related studies revealed that teaching with the help of Pjbl-STEM had a positive influence on students' creativity and attitudes towards scientific learning (Tseng et al., 2013), their motivations (Siew et al., 2015), and their academic achievements (Çevik & Abdioğlu, 2018; Lou et al. 2014; Nurtanto et al., 2020). Consequently, as a result of the integration of the Pjbl and STEM approaches, students can transfer knowledge between four disciplines thanks to the projects they have produced. In this way, meaningful learning occurs, and this has a positive influence on students' attitudes and increases their probability to choose the STEM professions for their future careers (Tseng et al., 2013).

As is known, Pjbl-STEM education, which is grounded on the social constructive theory, focuses on the real-life problems of students, or on socio-scientific issues to create a more sustainable world for humanity and as well as nature. Socio-scientific issues are those which occupy the agenda of Society 5.0, which are based on science, and which can be explained or solved with the help of science (Eastwood et al., 2012). In addition, in today's society, a number of socio-scientific issues have made science and other sciences more important. These issues mentioned above as Society 5.0 issues are climate changes, ecological crisis, renewable energy sources, nuclear energy, hydroelectric power plants, and genetic cloning. Moreover, in literature, socio-scientific issues are reported to have a positive influence on science literacy (Driver et al., 2000). Besides raising the consciousness of responsible citizenship, socio-scientific issues help students solve the problems of society as well (Zeidler et al., 2005). Therefore, in the present study, for the purpose of increasing the 10th-grade students' awareness of 21st-century skills, and social issues, the Pjbl method involving the integration of the lesson subject of solid waste with STEM was applied to the students. Moreover, environmental issues, which are among essential topics on the agenda of Society 5.0 or in today's world, are now considered to be among the 21st-century skills under the heading of environmental literacy. In this study, with the help of the projects carried out using especially waste materials, the purpose was to have a positive influence on the students' sensitiveness to the environment.

In literature, studies conducted on Pjbl-STEM education are quite a few in number (Çevik, 2018; Lou et al., 2014). For this reason, the present study is thought to contribute to the related literature. In line with the purpose of the study, the following research questions were directed:

1. What is the influence of the project-based STEM activities on the development of the 10th-grade students' usage levels of 21st-century skills?
2. What is the influence of the project-based STEM activities on the 10th-grade students' views about the development of their 21st-century skills?

## Method

In this study, the pretest-posttest pre-experimental design without a control group was used. In this research design, the independent variable is applied to a randomly selected group before and after the experimental process (Karasar, 2006).

### Participants

The study group was made up of 24 10th-grade students attending a state high school in the city center of Diyarbakır Province of Turkey. While determining the study group, the easily accessible case sampling was used.

### Data Collection Tools

In order to collect the quantitative data in the study, the 21st-century Skills Usage Scale developed by Orhan Göksün (2016) was used. The scale included four sub-dimensions: cognitive skills with 17 items ( $\alpha=.877$ ), autonomous skills with six items ( $\alpha=.706$ ), cooperation and flexibility skills with six items ( $\alpha=.672$ ) and innovation skills with two items ( $\alpha=.818$ ). The total reliability coefficient of the scale was calculated as .892. Cognitive skills; processing and coding of the knowledge and being aware of the product that take place in the mental process, autonomous skills; integration of self-management, self-control, and ability to work individually or in groups, collaboration and flexibility; expanding collaborative activities success and learning environments, innovation skills; adaption to new technologies (Orhan Göksün, 2016). For the validity of the scale, the researcher, who was also the developer of the scale, asked for expert views and conducted exploratory and confirmatory factor analyses. In addition, for the purpose of evaluating the change in the participants' sensitiveness to the environment, the Environmental Sensitiveness sub-dimension of the Environmental Awareness Scale developed by Çetin and Yalçınkaya (2018) was used since this sub-dimension served the purpose of the present study. The reliability coefficient of this sub-dimension was calculated as .694 by the researchers.

Before the research process started, the related literature was reviewed for the interviews to be held by the researchers, and the indicators of the framework formed for the 21st-century skills by Partnership for 21st-Century Learning (P21, 2019) were taken into account. With the help of this framework, a question pool including 11 statements was prepared considering which 21st-century skill would be influenced by the activities to be carried out within the scope of the study. These statements were examined by experts from the fields of Science, measurement-evaluation, and language, and the experts agreed that a total of three statements were not appropriate. It was decided to remove these three questions that were thought to not serve the purpose of the research. Consequently, an 8-item interview form whose validity and reliability were ensured was used as the data collection tool in the study. This interview form was given to 16 students, who were asked to write down their views. In addition, based on the information about the students given by the teachers, in order to gather more detailed data, semi-structured interviews were held using the same questions with eight students who have good self-expression skills. Focus group interviews were conducted with these students. These interviews lasted approximately two hours in total.

### Application Process

During the applications, project-based STEM activities were carried out. Prior to the applications, the study groups were formed by dividing the students into groups of three in accordance with the order of the students in the class attendance list. Each group was given STEM projects in which waste materials were used. One of the groups was given three STEM projects, and all the other groups were given two STEM projects. This distribution was done in accordance with the

difficulty levels of the projects assigned. The activities carried out in this process were arranged in line with the steps of the project-based learning model (Stix and Hrbek, 2006). These steps were as follows:

1. Creation of the projects
2. Determining the groups and their roles,
3. Determining the needs regarding the sub-structures of the projects,
4. The teacher and students determine the criteria for evaluating the projects.
5. Preparing the necessary materials and developing the projects,
6. Students create their projects
7. Students prepare to present their projects.
8. Presentation of the projects,
9. Reflection and feedback.

In this process, the students were given a total of 17 project headings as can be seen in Table 1. These projects were selected by the researchers among stem projects on websites (<https://tr.pinterest.com/IowaSTEM/stem-fun-for-high-school/> and Youtube).

**Table 1**

*Projects Conducted By the Students Using Waste Materials*

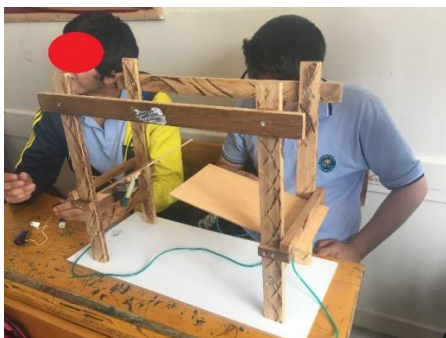
1-Hydraulic robot hand	10-Rocket
2-Hydraulic bridge	11-Solar panel
3-Drilling Machine	12-Periscope
4-Balloon car	13-Telescope
5-Small electric engine	14-Lift
6-Popcorn machine	15-Toy copter
7-Magnet engine	16-Thermos
8- Parachute	17-Endless waterfall
9-Torch	

The students prepared the STEM projects both at school and out of school. After the students in the study group completed their projects, they prepared reports about their projects and presented these reports to their classmates. In the study, the phase of preparation of the projects lasted four weeks in total. At the end of the applications, the 21st-century skills usage scale was applied to the students. Moreover, in order to determine the students' views, structured and semi-structured interviews were held with them. Consequently, the results of the analyses conducted allowed evaluating the development of the 21st-century skills of the participants.

Below are some photos taken in the application process in the study;

**Figure 1**

*Construction of the Hydraulic Bridge*



As can be seen in Figure 1, for the construction of the hydraulic bridge, the students used waste wood, expired injection needles, and serum pipes.

**Figure 2**

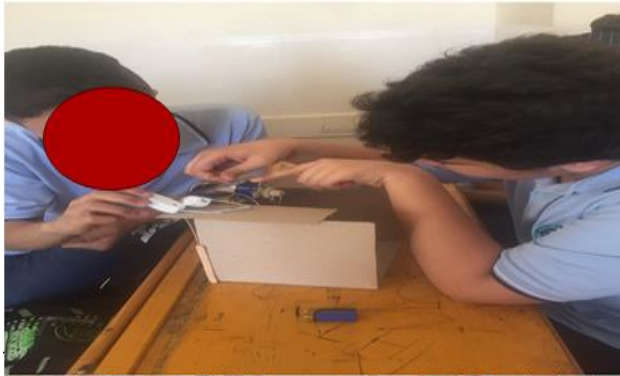
*Making a Simple Drilling Machine*



As can be seen in Figure 2, the students made a simple drilling machine by using expired injection needles, cables, and an old engine.

**Figure 3**

*Making a Lift*



As can be seen in Figure 3, the students used waste cardboard boxes, cables, a thread cone and an old engine to make a miniature lift that worked as a model.

**Figure 4**

*Students' Presentation of the Hydraulic Robot Hand*



As can be seen in the above figure, the students who completed their projects presented them to their classmates.

## Data Analysis

The obtained qualitative data were analyzed by using the method of inductive and thematic analysis. By using the thematic analysis method, the researcher focuses on searching for common codes and themes among the obtained data (Gibbs, 2007). Nvivo 12 was used to analyze qualitative data. Firstly, during this process, the students' opinions were coded and entered into the nodes in the Nvivo program. Subsequently, the nodes were grouped, and categories were created. Afterward, the categories are placed under the determined themes. For ensuring coding consistency, the research team reviewed the codes and reached a consensus by discussing the definition and the content of the created codes. The obtained qualitative data were analyzed by considering the indicators of the framework developed for 21st-century skills by Partnership for 21st-Century Learning (P21). In addition, direct quotations are included to reflect the opinions of the participants.

Nonparametric statistics were used in the quantitative data analysis, as the number of participants was less than 30 and could not represent the normally distributed universe (Büyüköztürk, 2016). For this reason, Wilcoxon's Signed Ranks Test, one of the nonparametric statistical techniques for dependent groups, was used to determine whether the pre and post-tests of the same group were different or not.

## Findings

As a result of the analysis of the data collected in the study, the following findings were obtained.

### Quantitative Findings Related to the Contribution of the STEM Projects with Waste Materials to the Development of the 21st-Century Skills of the Students

Table 2 presents the results of Wilcoxon's Signed Ranks Test regarding the total and sub-factor scores of the 21st-century skills scale applied before and after the application of the STEM projects.

**Table 2**

*Wilcoxon's Signed Ranks Test Results Regarding the Total and Sub-Factor Scores of the 21st-Century Skills Scale Applied Before and After The Application of the STEM projects*

	Posttest-Pretest	N	Mean rank	Sum of ranks	Z	p
Cognitive skills	Negative rank	13	8,42	109,50	-,868	,385
	Positive rank	10	16,65	166,50		
	Equal	1				
Autonomous skills	Negative rank	7	8,21	57,50	-2,023	,043
	Positive rank	14	12,39	173,50		
	Equal	3				
Cooperation and flexibility skills	Negative rank	3	12,00	36,00	-2,583	,010
	Positive rank	17	10,24	174,00		
	Equal	4				



Innovation skills	Negative rank	4	6,13	24,50	-1,476	,140
	Positive rank	9	7,39	66,50		
	Equal	11				
Total	Negative rank	6	10,83	65,00	-2,223	,026
	Positive rank	17	12,41	211,00		
	Equal	1				

Note. \*Based on negative ranks

According to the results in Table 2, there was a significant difference between the participants' total scores in the 21st-century skills scale before and after the application of the projects ( $p < 0,05$ ). When the rank totals of the difference scores were taken into account, it was seen that the difference was in favor of the posttest positive ranks. Accordingly, it could be stated that the STEM projects contributed to the development of the students' 21st-century skills. When the sub-factors were considered, it was seen that there was a significant difference between the pretest and posttest scores of the students regarding such sub-factors of the 21st-century skills scale as autonomous skills, and cooperation and flexibility skills ( $p < 0,05$ ). According to the rank totals of the difference scores, the difference was in favor of posttest positive ranks. Therefore, it could be stated that the STEM projects contributed to the development of such 21st-century skills of the students as autonomous skills and cooperation and flexibility skills. On the other hand, no significant difference was found between the pretest and posttest scores in terms of such sub-factors of the 21st-century skills scale as cognitive skills and innovation skills ( $p > 0,05$ ).

Table 3 shows the results of Wilcoxon's Signed Ranks Test regarding the pretest and posttest scores in the sub-dimension of environmental sensitiveness applied within the context of environmental literacy (P21), which is one of the themes in the 21st-century learning framework.

**Table 3**

*Wilcoxon's Signed Ranks Test Results Regarding the Environmental Sensitiveness Scale Sub-Dimension Scores before and after the Application of the Projects*

Posttest-Pretest	N	Mean rank	Sum of ranks	Z	p
Negative rank	4	8,63	34,50	-2,004	,045
Positive rank	13	9,12	118,50		
Equal	7				

Note. \*Based on negative ranks

According to the results in Table 3, there was a significant difference between the students' pretest and posttest scores in the environmental sensitiveness scale ( $p < 0,05$ ). When the rank totals of the difference scores were examined, it was seen that the difference was in favor of the posttest positive ranks. Accordingly, it could be stated that the STEM projects contributed to the development of the students' environmental sensitiveness.

### **Qualitative Findings Related to the Contribution of the STEM Projects with the Use of Waste Materials to the Development of the Students' 21st-Century Skills**

Table 4 shows the themes, categories, and codes of students' views on the development of 21st-century skills in STEM projects.

**Table 4**

*Codes, Categories, and Themes Regarding the Contribution of the STEM Activities to the Development of the 21st-Century Skills*

Theme	Categories	Codes	f
Learning and innovations skills	Communication and Collaboration	Exchange opinions	28
		Helping each other	
		Develop empathy	
		Making a work-sharing	
		Take responsibility	
		Communicating with teachers	
		Communication with peers	
	Problem-solving	Solving problems in the project	20
		Solving problems in daily life	
	Creativity	Brainstorming	18
		Imagination	
	Critical thinking	Concretizing	4
		Raise awareness	
Life and career skills	Responsibility	Making a work-sharing	19
		Sense of mission	
Environmental Literacy	Environmental Awareness	Environmental pollution	19
		Recycling	

As can be seen in Table 4, within the context of learning and innovations skills, the students thought that their communication and collaboration skills developed thanks to the projects. Many students stated that since they carried out the project with group work, they constantly exchanged ideas with their friends and teachers during this process, so their communication and collaboration skills could be improved. Students also think that their communication and collaboration skills are improved, as they mostly empathize with their friends, share tasks and help each other in group work. Two of the students reported that they did not favor group work in their previous projects. However, the two students stated that they developed more positive views about group work and cooperation thanks to the projects they carried out in the present study. In relation to this, the views of one student reported the following views:

*"We all had a say in the group work, we were paying attention to everybody's opinion, and I think our collaboration skills have increased since we are running a joint project."*

*"I didn't like collaboration very much. Then I saw that I got along well with my friends. Although there were disagreements on some issues, they were resolved, and we were pleased when we finalized the project. Especially when we present or listen to what our friend presents, we developed a sense of empathy. "*

Most of the students said they experienced problems in the process, and they believed their problem-solving skills might have developed while seeking solutions to these problems. Some of the students stated that they managed to overcome the problems they experienced in the project process thanks to their individual efforts as well as with the help of collaboration. In addition, the students thought they should find more practical solutions to daily life problems. Two of the students reported that their problem-solving skills did not develop because they conducted projects similar to those which had already been done and shared on the Internet. In relation to this, one student reported the following views:

*"We faced a number of problems in the process related to the materials and other things. Consequently, we try something, but we may do it wrongly. However, in order to complete the project, we had to correct it. For this, we think about it over again, and this develops our skills."*

Most of the students stated that before forming their projects, they searched the subjects they had selected. In this process, according to the students, they thought about how to develop their projects, which might have consequently helped develop their creativity. The students also stated that they brainstormed with their friends about the project. A few students think that they have done similar projects that they researched on the Internet; therefore, their creativity has not developed. In relation to this, some students' views were as follows:

*"Yes, because we stretched our imagination about how to do our work better, and this contributed to our creativity development."*

*"For example, I think our creativity has improved because we think about which materials we will use and which ones we should use while doing the activities."*

Some students have mentioned critical thinking skills. The students reported that the contents of the courses given at school were mostly theoretical and that they thus did memorization. However, they stated that the projects concretized what they had learned in other courses. Moreover, according to the students, it was possible to associate daily life with the theoretical knowledge they acquired via the courses. In relation to this, one student reported the following views:

*"We used to only memorize, and we always failed to see the logic behind the courses. However, after we did these activities within the scope of the projects, I understood that the knowledge we get via applied courses becomes more permanent."*

Within the context of life and career skills, almost all the students reported that their responsibility skills developed in the process of conducting the projects. The students thought that their responsibility skills developed because they had certain duties which they tried to do in the process. Some of the students stated that they did their duties just because they felt responsible for their friends while conducting the project with their friends in the group. In relation to this, one student reported the following views:

*"Since my childhood, I had never been a responsible person. I can confess that I had never done my homework. However, as it was group work, other students unintentionally force you to do something. Therefore, you start undertaking a responsibility, and you try to do it."*

Within the context of environmental literacy, the students stated that the project had a positive influence on their environmental awareness. Only one student reported that s/he already had environmental awareness and that the project did not cause any difference. It was seen that the students referred especially to recycling. The students stated that the projects changed their viewpoints regarding waste materials and garbage and that rather than regarding waste materials like trash, they learned how to transform these waste materials into new materials to facilitate their daily lives. Furthermore, they pointed out that recycling helps decrease costs. Some of the students' views were as follows:

*"Now, I don't consider waste materials to be garbage. I mean I find these materials beneficial and regard them as materials to be used in projects."*

*"Instead of causing environmental problems with our wastes, we can meet our needs with the help of these wastes, and this changed my viewpoint."*

Some of the students stated that the projects made them more sensitive to environmental pollution. One of the students reported that they had to become conscious of environmental pollution to leave a better world for future generations and that the projects helped raise this consciousness. The student reported the following views:

*"We know that the world is a place where we live, and the world is inherited from the previous generation and left for the next. Our children and their children will live here. We have to keep the world clean because what makes the world dirtiest is generally people's*

*insensible behaviors. In the past, I wasn't so sensitive to the world at all, and this project made me more sensitive to the environment."*

The ways the students followed in their STEM projects, the codes related to the technology used, and the 21st-century skills represented by these codes can be seen in Table 5 below. The codes, categories, and themes related to the path followed and the tools used by the students in STEM projects are shown in Table 5.

**Table 5**

*Codes, Categories, and Themes Related to the Way Followed and the Tools Used in STEM Projects*

The way followed in the project process			
Themes	Categories	Codes	f
Information, Media, and Technology Skills	Information literacy	Doing research	13
Learning and Innovation Skills	Creativity	Brainstorming	5
	Critical thinking	Doing observation/experiment	4
The tool used			
Information, Media, and Technology Skills	Technology skills	Internet	22
		Mechanical tools	6

As can be seen in Table 5, it is seen that students mostly refer to information literacy in the context of information, media, and technology skills regarding the way they followed in the project development process. In the context of learning and innovation skills, they referred to creativity and critical thinking. The students stated that they did research regarding their projects especially via the Internet and obtained information from different sources. In addition, it was seen that the students emphasized information reliability in the process of doing research. The students also reported that they reached a wide variety of videos and information while doing research on their projects via the Internet; that they thus examined the comments on the Internet to confirm the correctness of the information; and that they searched for other different sources. In relation to this, one of the students' views were as follows:

*"Today, it is very easy to reach information because we have the Internet. Everybody uploads what they know, and what is difficult is to find the current information among all the information sources. We also looked at the comments while watching the videos on YouTube. We got many ideas by watching these videos, and we asked friends to confirm whether these ideas were correct or not. In this phase, we did not have problems at all because we know how to make good use of the Internet. As a result, we reached the correct information."*

Students also mostly referred to their technology skills regarding what tools they used and why during the project development process. The students stated that they especially used the internet for research and used several mechanical tools during the production of the products. In relation to this, some of the students' views were as follows:

*"We also used technology and other tools like the drilling machine. It transforms the electric power into kinetic energy. This is also true for the bridge. It lifts with the help of pressure."*

In general, it could be stated that there were positive changes in the students' usage of the 21st-century skills as well as in their views about these skills and the process.

## Discussion

The present study investigated the influence of Pjbl-STEM education on the 21st-century skills of high school 10th-grade students.

In the light of the findings of students' interviews (see Table 4 and Table 5) and the results of the tests (see Table 2 and Table 3) applied during the teaching process, it can be stated that the 21st-century skills of the students have developed. These skills were communication and cooperation (Capraro et al., 2013; Krajcik et al., 1999; Krajcik & Czerniak, 2014; Lou et al., 2017; Schaller & Hadgraf, 2013; Şahin, 2015); autonomous skills, environmental sensitiveness, responsibility (Connors-Kellgren et al., 2016; Şahin, 2015), creativity (Lou et al., 2017; Şahin, 2015; Tseng et al., 2013), concretizing skills (Çınar et al., 2016; Gürbüz and Karadeniz, 2020) and problem-solving (Cooper & Heaverlo, 2013; Çakıcı & Türkmen, 2013; Hickey, 2014; Netwong, 2018; Şahin, 2015), respectively.

The development especially in the students' autonomous skills and cooperation skills was an expected result in the study. The reason is that the students not only did group work but individually undertook responsibility as well. In addition to this, since Pjbl-STEM is a constructivist approach, it gives the students autonomy in the classroom (Dogan & Robin, 2015, s.78). Therefore, students can work independently inside and outside the school, and communicate with their groups, which cause a moderate increase in autonomy, cooperation, and communication skills.

Another essential product of this study is increased creativity (Lou et al., 2017; Strong, 2013) and critical thinking skills. Creativity and critical thinking (Rogers & Portsmore, 2004; Şahin, 2015; Zoller, 1991) skills are crucial skills developed using Pjbl-STEM. These skills can be improved while the students try to find innovative solutions via designing a product to solve real-life problems. On the contrary, some students claimed that they couldn't improve their creativity and critical thinking skills because of finding ready information on the internet. According to existing literature, many reasons can cause this, such as poor content preparation (Ejiwale, 2013), poor preparation of teachers in STEM classes (Akuma & Callaghan, 2019; Margot & Kettler, 2019), lack of teaching different ways of getting knowledge (Ejiwale, 2013).

The results of the analyses applied in the study demonstrated that in the process of developing the STEM projects, the students did brainstorming to solve the current problems, conducted research, and obtained the necessary materials. This is because the students worked together, strove on real-life issues, and tried to put forward the possible solution. In addition to that, it was seen that only a few students did experiments and observations. Another finding was that most of the students used the Internet to get information. As can be understood from its definition, STEM is a science-based method of education which deals with real-life problems by covering a number of disciplines. Therefore, in the present study, the students put forward several hypotheses to seek answers to their questions while discussing the socio-scientific subjects in the process of conducting the projects; consequently, the students developed their skills such as expressing thoughts (Krajcik & Blumenfeld, 2006), using the Internet and doing experiments (Connors-Kellgren et al., 2016), which were also supported with the findings reported in the literature.

Using real-life or ill-defined authentic problems embedded in the project also help students to improve their life skills, such as problem-solving skills (Han et al, 2014). As mentioned before, problem-solving skill is listed in 21st-century skills, which is one of the needed skills for real life. It is also a way of encouraging students to create concrete projects to solve the problems in the community (Netwong, 2018).

One important finding obtained in the present study was that the educational applications carried out within the scope of the solid waste Pjbl-STEM projects developed the students' environmental sensitiveness. In terms of this environmental sensitiveness, the difference was in favor of the posttest according to the results of the quantitative analyses, and the participants' environmental sensitiveness was found to develop. This finding was also supported by the qualitative findings obtained in the study. Most of the students reported that they began to be sensitive to environmental problems that they had never been aware of. One reason for this was that the projects

used for the STEM education were based on real-life problems or socio-scientific subjects raised the students' consciousness of responsible citizenship (Connors-Kellgren et al., 2016; Cooper & Heaverlo, 2013;; Lou et al., 2017; Zeidler et al, 2005). So that Pjbl-STEM can develop life skills such as problem-solving skills and empathy for sustainable issues (Department of Education and Skills, 2020), which are crucial skills for Society 5.0.

Another finding obtained in the study was that there was an increase in the students' levels of concretizing scientific concepts. There are also similar findings in previous researches related to the positive effects of STEM on concretizing skills (Çınar et al., 2016; Gürbüz & Karadeniz, 2020). Students fail to associate certain scientific abstract concepts with their daily lives, and they naturally have difficulty in relating science to their own lives. For this reason, science is considered to be among difficult subjects throughout the world, and it is seen that students avoid choosing a career in the field of science (OECD, 2016; Stine & Matthews, 2009). However, several studies aim to change the negative motivations, interests, and attitudes of students regarding science and STEM fields by encouraging them to learn socio-scientific subjects with the help of STEM projects. Hence, giving more place especially to STEM fields and to the 21st-century skills in school curricula is considered to be important for students' future careers.

### Conclusion and Suggestions

The results of the present study revealed that the STEM activities involving the use of waste materials had a positive influence on the 10th-grade students' usage and development of 21st-century skills, which are among important concepts of Society 5.0 and Industry 4.0. This is a fairly important result in that an increase in the number of individuals with 21st-century skills is an important factor for the development of societies. Based on the findings obtained in the study, it is highly likely that the number of individuals to serve society in this respect increased. With the help of these activities, the students were made aware of their own qualifications by learning via entertainment. Societies with individuals who can evaluate themselves and who can make decisions regarding themselves are open to development. The present study was conducted for that purpose, and positive results were obtained.

According to the results following suggestions can be made:

- Educational institutions should give more importance to project-based STEM education to increase the effectiveness of Pjbl-STEM activities on the development of 21st-century skills.
- the school curricula should include more contents related to the development of 21st-century skills.
- In addition, in order to increase students' environmental sensitiveness and to raise their sustainable environmental consciousness, environmental education should be included as an obligatory course in all school curricula.
- For all these purposes to come true, it would be necessary to develop the sub-structures necessary for STEM applications in all elementary school and secondary school institutions.
- Since the study is limited to 10th-graders science curriculum and only one high school in Diyarbakir. It is thought that applying Pjbl-STEM applications to all levels and also to a more significant sample will be more beneficial.

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