Journal of Turkish Science Education, 2022, *19*(1), 163-179.
DOI no: 10.36681/tused.2022.116

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

Engineering Design-based Activities: Investigation of Middle School Students' Problem-Solving and Design Skills*

Lütfi Uzel[1], Sedef Canbazoğlu Bilici[2]

[1]*Ministry of National Education, Turkey, ORCID ID: 0000-0001-9541-2208*
[2]*Aksaray University, Turkey, ORCID ID: 0000-0001-7395-6984*
**This study is a part of the master' thesis of Lütfi UZEL (supervised by Assoc. Prof. Dr. Sedef CANBAZOĞLU BİLİCİ) entitled "Evaluation of the impact of engineering design-based activities performed in 6th grade "matter and heat" unit on problem-solving and design skills".*

ABSTRACT
The purpose of this research is to examine the effects of engineering design-based activities carried out in the sixth-grade Matter and Heat unit on the problem-solving skills of students, and the changes in the designing skills of students during these activities. This research, conducted by following the one-group pre-test – post-test quasi-experimental design, was carried out with 23 students enrolled in a public school. Within the scope of the research, activities structured in line with the Matter and Heat unit learning outcomes were carried out for five weeks. The effect of the activities on the problem-solving skills of students was evaluated with the 'problem-solving skills test'. During the activities, 'worksheets' and 'design products' were used to evaluate the designing skills of students. The data obtained from the problem-solving skills test were analyzed using the Wilcoxon signed-rank test. The engineering design process rubric was used to evaluate the changes in students' design skills during the engineering design-based activities.The results showed that there is a statistically significant difference between students' pre-test and post-test scores in the problem-solving skills test. It has been determined that engineering design-based activities carried out within the framework of the real-world problems contribute to the increase of engineering design skills of middle school students.

ARTICLE INFORMATION
Received:
25.03.2021
Accepted:
09.10.2021

KEYWORDS:
Engineering design process, problem-solving skills, design skills.

Introduction

The rapid changes in the fields of science and technology in the 21st century multiply human needs and make the problems people face in daily life more complex. In solving these complex problems, the knowledge and skills of a single discipline do not suffice and there is a need for a transdisciplinary perspective (Wang, 2012). Moreover, in solving problems, it is important that individuals possess 21st-century skills (problem-solving, creativity, critical thinking, working in cooperation, innovation, etc.). In this context, education reforms are implemented to raise individuals who will play roles in solving global problems. Education reforms emphasize the acquisition of problem-solving and creative thinking skills by individuals. Individuals are expected to integrate these skills into their daily lives (Demir, 2015; Ernst & Haynie, 2010; Wells, 2008). STEM (Science, Technology, Engineering, and Mathematics) education is considered to be an opportunity for individuals to acquire skills such as problem-solving and creative thinking (Battelle for Kids, 2019; Sarı et al., 2020; Suratno et al., 2020). Students' research and inquiring, their solving of problems they encounter in real-world and designing products to solve problems is possible through a atransdisciplinary integration of science, technology, engineering, and mathematics (Bozkurt Altan, 2018). In this context, students must experience educational practices where they can acquire these skills (Felix, 2016; Miaoulis, 2009). Especially, the experience of middle-school students with the discipline of engineering will make a great contribution to the raising of problem-solving, creative-thinking, and technologically literate individuals.

In Turkey, STEM education was not emphasized explicitly in the 2013 middle school science curriculum (Ministry of National Education [MoNE], 2013), but the curriculum contained dimensions that were directly related to STEM education such as project designing and equipping students with science process and life skills. However, the 2017 draft middle school science curriculum for 3-8th grades explicitly included science and engineering activities (MoNE, 2017). In addition to the objective of raising individuals with scientific literacy, this draft curriculum aimed to educate individuals to be able to transfer their skills and information, acquired by blending science with other disciplines, and by designing products. In contrast with the 2017 curriculum, in the science curriculum updated in 2018, this field was approached as 'science, engineering and entrepreneurship practices' and was no longer a unit, with unit outcomes from fourth- to eighth-grade structured in line with this. The aim of these changes encompassed making students individuals who can produce solutions to problems or needs of real-world, design products by using the information and skills they acquired in this process, add value to and market their designed products as well as having the students develop themselves, all by ensuring a dynamic interaction between the disciplines of science, technology, engineering and mathematics (MoNE, 2018). The explicit inclusion of 'science, engineering, and entrepreneurship practices' to the curriculum can be identified as a factor supporting STEM education in middle schools in Turkey. Le Thi Thu et al. (2021) performed a bibliometric analysis of research into STEM education in middle schools in the last 20 years. In this research field, following the United States, Turkey is the country with the second-highest number of publications. There has been a notable increase in the number of studies, especially in the last five years. Studies focused especially on the impact of STEM education practices on students' academic success, attitudes towards STEM career professions, and STEM awareness (Baran et al., 2019; Elmalı & Balkan Kıyıcı, 2017; Özer & Canbazoğlu Bilici, 2021;). These variables which were the focus of these studies are certainly important for STEM education. The information of students on the discipline of engineering, which is included in the curriculum as well, is more limited compared to other STEM disciplines. Students need to experience the engineering design process with engineering design-based activities.

It is emphasized that inquiry-based activities in science education should be blended with the engineering design process (National Research Council [NRC], 2012). In contrast to other pedagogical approaches, in STEM education, engineering and design come to the fore (Akarsu et al., 2020; Jolly, 2014). Design is indicated as the most important dimension of the engineering enterprise, the aim of which has been to identify and satisfy economic, social, and cultural needs throughout history (National Academy of Engineering [NAE] & NRC, 2009; Petroski, 1996). Engineering is defined as design realized within criteria and constraints (NAE, 2010). The 'Technology and Engineering Literacy Framework' report prepared by the National Assessment Governing Board (2010) defines engineering as a design process. In design, which is the approach of engineers to produce solutions for needs or problems, a single method is not employed and the produced solutions incorporate a systematic process (NAE, 2010; NAE & NRC, 2009; NRC, 2012). This process referred to as the engineering design process, is defined as 'the approach used by engineers to identify the best way to solve engineering problems, serve a given purpose and create a tool or process' (NAE & NRC, 2009, p. 38). Engineering design-based activities help students who actively partake in them to meaningfully learn the disciplines of science and mathematics, raise their awareness of engineering and engineers' works as a career and understand engineering design processes (NAE & NRC, 2009). In general terms, the engineering design process includes the processes of defining and solving the problem (NRC, 2009). Syukri et al. (2018) state that though identifying and solving the problem is important in the engineering design process, studies investigating the impact of this process on students' scientific problem solving are limited. Engineering design-based activities are not restricted to only ensuring that students think about and work on real-world problems. They also ensure that students use their mathematical and scientific knowledge in predicting, analyzing, and solving engineering problems (Fan & Yu, 2017). In Turkey, engineering design-based science education activities generally have been carried out as part of STEM education. Some research considered the extent to which STEM education-based activities have an impact on prospective science teachers' and students' problem-solving, scientific creativity, critical thinking, decision-making, higher-order thinking and science process skills (Bozkurt, 2014; Fan & Yu, 2017; Hacıoğlu, 2017; Pekbay, 2017). Research also examined individuals' perceptions of, attitudes towards and interest in engineering (Ünlü & Dökme, 2016; Pekbay, 2017; Yıldırım & Türk, 2018). Özer (2019) identified the impact of Algodoo-based activities within the sixth-grade force and motion unit on students' engineering design skills and conceptual understanding. The development of engineering design-based activities has a significant role in understanding the application of the four STEM disciplines in the problem-solving process (Chiang et al., 2020). Alfiana et al. (2021) follow three steps; initial study, product development, and product testing to improve high school students' problem solving skills on heat and temperature topics. Many middle school students still have learning difficulties on heat and temperature topics (Sarıkaya, 2019; Yılmazel, 2020). In this research, engineering design-based activities were also carried out within heat and temperature topics under "matter and heat" unit. This study aims to examine the impact of engineering design-based activities within the sixth-grade Matter and Heat unit on students' problem-solving and engineering design skills. In line with this aim, the research questions are the following:

1. Is there a statistically significant difference between the problem-solving skills of students before and after engineering design-based activities?
2. How do sixth-grade students' design skills change during the process of engineering design-based activities?

Methods

Research Design and Context

A "one-group pretest-posttest quasi-experimental" design was used to examine the impact of engineering design-based activities within the sixth-grade Matter and Heat unit on students' problem-solving skills, and the changes in students' design skills during the activities. Pre-test and first scoring of activities were accepted as the starting point on the effectiveness of engineering-based activities without comparing any control group. In the first two weeks of the study (8*40 min), students were informed about engineers, engineering, engineering design process, and STEM education. Then, with the engineering design process game presented in Figure 1, it was aimed that students learn the engineering design process. In the game, the engineering design process was drawn on a piece of colored pasteboard. The steps of the design process were written on small pieces of cardboard and attached to the pasteboard with the help of hook-and-loop fasteners. The small pieces of cardboard with the steps written on them were placed irregularly on a desk. Then, students were asked to correctly complete the steps that were left empty on the pasteboard. In this process, the steps of the engineering design process were discussed. It was emphasized that this loop was dynamic and the process could be followed by returning from one step to the other.

Figure 1

Engineering Design Process Game

As indicated in Table 1, in the third week of the study, the pre-test of the problem-solving skills test (80 min) was applied to students. Following this, five activities structured in line with real-world problems were performed in the science course (five weeks, 20-course hours). In the last week of the study, the post-test of problem-solving skills test (80 min) was applied to students again.

Table 1

Research Process

Week	Content
1-2.	➢ Providing information about the engineering design process and activities to be performed in the research
3.	➢ Problem-solving Skills Test (pre-test)
4-8.	➢ Performing the engineering design-based activities ❖ Week 4: Activity 1 - Thermometer ❖ Week 5: Activity 2- Anti-Freezing Milk Tank ❖ Week 6: Activity 3- Let There Be No Unheated Home ❖ Week 7: Activity 4- Struggle Against Cold Weather Conditions ❖ Week 8: Activity 5- Lemon Carrying Containers
9.	➢ Problem-solving Skills Test (post-test)

Researchers obtained the ethical committee report for this study the processes of which are detailed in Table 1. Moreover, in the first week of the study, researchers informed parents and students on the research process and obtained permission for students' participation in the study through parental consent forms.

Sample of the Study

The sample of the study consisted of 23 sixth-grade students in a middle school located in a lower socio-economic environment in the district of Guzelyurt, Aksaray. The study employed the convenience sampling method in identifying participants. The study took place in the school where one of the researchers serves as a science teacher, with students attending the researcher's science course.

Data Collection

The data collection tools of this study are 'Problem-solving Skills Test (PsST)', 'worksheets' and ‘design products'.

Problem-Solving Skills Test (PsST)

PsST (Pekbay, 2017) was used to determine the impact of design-based activities on students' problem-solving skills as pre-test and post-test in this study. PsST consists of 18 questions, six about students' decision-making processes, six about their system analysis and design processes, and six about their problem-solving process. The mean difficulty of the test was calculated to be 0.34 with the test including 10 difficult, seven average, and one easy question. The Cronbach alpha reliability coefficient was calculated as .86 by Pekbay (2017). In this study, the Cronbach alpha coefficient was calculated as .95.

Worksheets and Design Products

The study employed worksheets and the student products that resulted from the activities to determine the impact of engineering design-based activities on students' design skills. In developing worksheets, the researchers followed the engineering design process steps recommended by Hynes et al. (2011). Before determining the real-world problems used in the activities, we asked students to list for a week the problems they faced in the real world. We then designed the activities by taking into account the students' responses and the context of Guzelyurt where the students live. For instance, houses shown in Figure 2 are unique architectural structures of the district of Guzelyurt. In most of these houses consisting of a ground floor and a first floor, the ground floor is constructed with rubble stone and the upper floors with smooth cut stone. Downstairs are used as cellars in these houses. As the altitude of the district center is high, the winter season lasts quite long and is cold. In line with this, for instance, in one of the activities of the study, we provided cases that emerge from the heating of homes and storing products in cellars. A table of learning objectives (Appendix) related to the five activities was prepared for the content validity of the activities. The table of learning objectives shows how each activity covers the disciplines of science, technology, engineering, and mathematics in terms of the curriculum. Initial versions of the activities were sent to two researchers studying STEM education. Experts reviewed the activities and provided feedback on the comprehensiveness of the activities. Furthermore, they examined in detail the steps of the engineering design process. The activities were finalized in line with experts’ comments and suggestions.

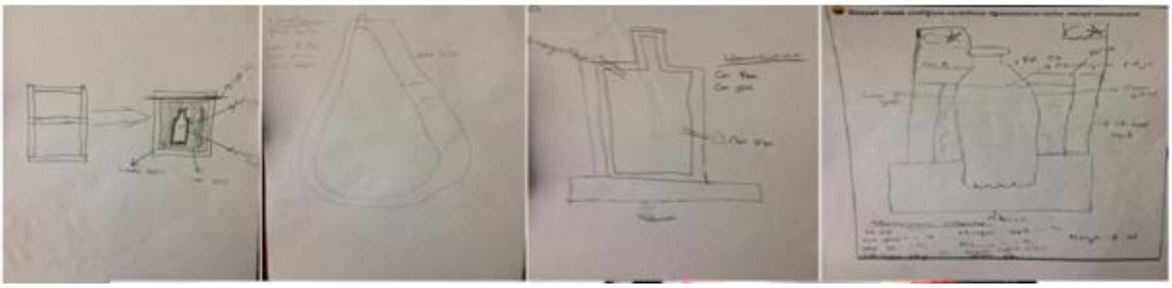
Figure 2

Examples of Houses in Guzelyurt

In the activities, students, working in groups of three and four, identified the problem in the case assigned to them and then developed possible solutions to the problem, taking into consideration also the relevant criteria and constraints such as capacity, temperature, cost, endurance, aesthetics and time. Stating their ideas about possible solutions individually, group members determined the best solution as a group. They explained why they chose the best solution among possible solutions by providing their reasons. Then, as shown in Figure 3, groups drew the prototypes of their designs.

Figure 3

Examples of Group Design Drawings



Groups designed in line with the prototypes they drew. In the end, groups presented the designs and each design was evaluated using the engineering design process rubric (NASA, 2015, p. 33). Strong and weak aspects of their designs were indicated to the groups, ensuring that they stated the changes they would make if they had a chance to redesign.

Figure 4

Example from Group Activities

During the activities, the researchers observed whether students would compromise on criteria and constraints. For example, some groups preferred to increase the cost and create a more durable design, whereas other groups preferred to keep the cost at a minimum, thereby compromising on the endurance criterion. The researchers gave students sufficient space on worksheets so that they could take notes of the work done in each step of the engineering design process. The researchers also warned students that they should not proceed to another step before completing the current one. Moreover, the researchers provided the materials to be used in the activities structured to be carried out with simple materials and guided students in their process of developing products.

Data Analysis

Analysis of PsST

The scoring proposed by Pekbay (2017) was followed to evaluate the pre-test and post-test scores. The responses of sixth-grade students to questions in PsST were graded as 3 (correct), 2 (partially correct), 1 (wrong) and 0 (empty). Questions with only one correct answer (Questions 1, 4, 8, 9, 11, and 15) were coded as correct (3) - false (1), while other questions were coded as correct (3) - partially correct (2) - wrong (1). If the student left the question unanswered, the question was coded as (0). In the grading of the tests completed by students, the highest possible score was 54 and the lowest possible score was 0. To check the normal distribution of the data, the values of skewness-kurtosis and the Shapiro-Wilk test recommended for a sample size below 30 (Althouse et al., 1998) are used in this research. Descriptive statistics of students' pre-test and post-test scores obtained from PsST are presented in Table 2.

Table 2

Descriptive Statistics of Students' Pre-test and Post-test Scores

	N	Mean	Skewness	Kurtosis
Pre-test	23	33.17	-.14	-.47
Post-test	23	37.04	-.96	-.71

According to Table 2, the data is normally distributed because the value of skewness and kurtosis are between -1 and +1 (Morgan, Leech, Gloeckner, & Barrett, 2004). The Shapiro-Wilk test is also used to test normality. Results of the Shapiro-Wilk test for normality results are shown in Table 3.

Table 3

Normality Test Results based on PsST Pre- and Post-test Scores

	Shapiro- Wilk		
	Statistic	df	p
Pre-test	.94	23	.19
Post-test	.94	23	.23

The skewness and kurtosis coefficients (Table 2), and p values greater than .05 ($p_{pre-test}$:.19>.05, $p_{post-test}$:.23>.05), and the result of the Shapiro-Wilk test (Table 3) were examined. Pre- and post-test scores indicated a normal distribution (Razali & Wah, 2011). However, the study employed the Wilcoxon signed ranks test as its sample included less than 30 individuals, even though the pre-test and post-test data indicated a normal distribution (Elliott & Woodward, 2007; Usta &Yılmaz, 2020).

Analysis of Worksheets and Design Products

The engineering design process rubric (NASA, 2015, p. 33) was used to evaluate the changes in students' design skills during the engineering design-based activities process. The rubric includes six criteria (identifying the problem, constructing a prototype, developing possible solutions, selecting the best possible solution, testing and evaluating the solution, communicating the solution) and three levels (1 point: below target, 2 points: at target, 3 points: above target). To interpret the arithmetic means of the groups obtained from each criterion after the activities, we used the class width as proposed by Kan (2009). In calculating class width, the difference between the largest value, 3, and the smallest value, 1, was divided by 3, the group number, thereby giving the evaluation range as 0.66. In this context, the group ranges were set as *2.34-3.00 above target*, *2.33-1.67 at target*, *1.00–1.66 below target*, and used in interpreting arithmetic means.

Findings

The Impact of Engineering Design-based Activities on Sixth-Grade Students' Problem-solving Skills

To answer the research question 'Is there a statistically significant difference between problem-solving skills of students before and after engineering design-based activities?', we performed PsST as pre-test and post-test. Descriptive statistics values from PsST on students' pre- and post-activities problem-solving skills are presented in Table 4. These values show that students' post-test scores exceeded their pre-test scores. Moreover, the lowest score in the pre-test was 10.00 whereas this was 16.00 in the post-test.

Table 4

Results of Descriptive Statistics regarding Students' Pre- and Post-test Scores of the PsST

	N	Mean	Std. Deviation	Minimum	Maximum
Pre-test	23	33.17	11.02	10.00	51.00
Post-test	23	37.04	9.59	16.00	51.00

We performed the Wilcoxon signed ranks test, a nonparametric test, to see if there was a significant difference between students' pre- and post-design-based activity PsST scores. The results of the Wilcoxon signed ranks test are presented in Table 5.

Table 5

Results of the Wilcoxon Signed Ranks Test regarding Students' Pre- and Post-test Scores of the PsST

	N	Mean Rank	Sum of Ranks	z	p
Negative Ranks	4[a]	4.75	19	-3.36[d]	.00*
Positive Ranks	17[b]	12.47	212		
Ties	2[c]	-	-		

Note. [a] Post-test < Pre-test, [b]Post-test > Pre-test, [c] Post-test = Pre-test, [d] Based on negative ranks. * p < .05

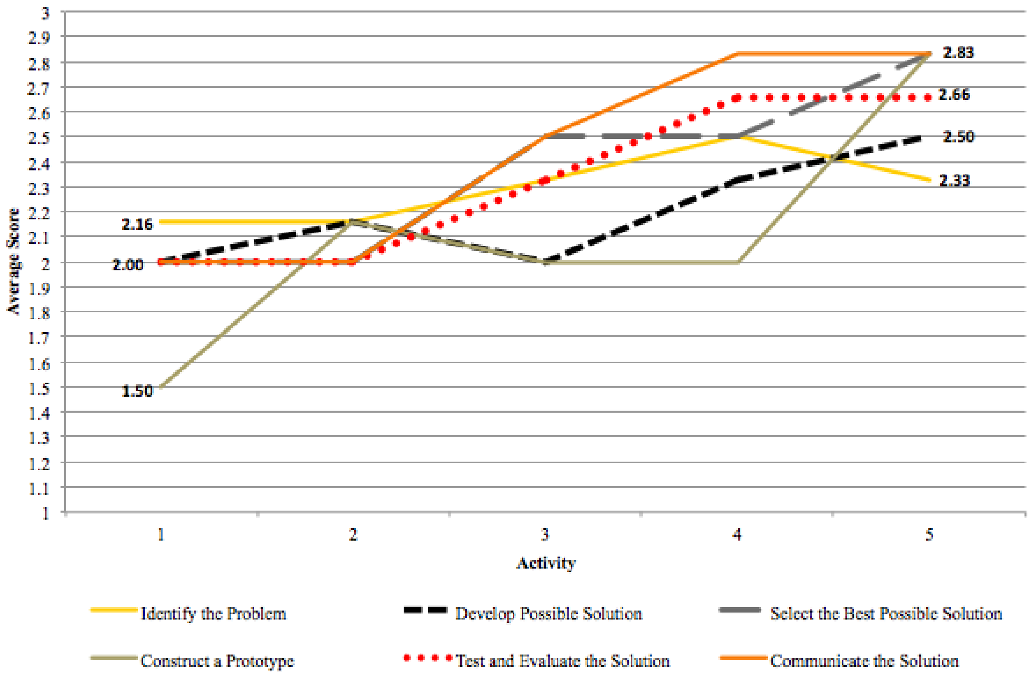
The results of the analysis in Table 5 show that there was a significant difference between students' problem-solving pre- and post-test scores (z= -3.36; p<.05). When mean ranks and the sum of ranks were taken into consideration, the negative ranks value was 4 in favor of the post-test, the positive ranks value was 17 and the value of the ties was 2. These values show that for 17 students, corresponding to 74% of the sample group, post-test scores exceeded pre-test scores whereas, for four students, post-test scores were inferior to pre-test scores. The analysis result reveals that there is a statistically significant difference between the PsST pre-test and post-test scores of the participating students (z= -3,36, p=0.001< 0.05). Taking into consideration rank averages and totals of score differences, it emerges that the observed difference is in favor of positive ranks, that is, the post-test score. According to these findings, it can be said that engineering design-based activities have an important impact on developing students' problem-solving skills. Moreover, the effect size value (r= .70) calculated to determine the effect size after the difference between pre-test and post-test scores was found to be significant shows that the difference between scores has a large effect size.

Changes in Sixth-Grade Students' Design Skills during Engineering Design-Based Activities

Worksheets and products that resulted from the activities in the context of the research question 'How do sixth-grade students' design skills change during engineering design-based activities', which were followed through the activities performed with students, were graded using the engineering design process rubric. The distribution of groups' average scores per activity for steps of the design process in the rubric is presented in Figure 5.

Figure 5

The Distribution of Groups' Average Scores Per Activity for Steps of the Engineering Design Process



As seen in Figure 5, in the thermometer activity (Activity 1) students received 2.16 points in identifying the need or problem step, 1.50 points in constructing a prototype step, and 2.00 points in other steps. In this context, in the thermometer activity, which was the first activity, students were on or above target in all steps except for constructing a prototype step. In the anti-freezing milk tank activity (Activity 2), students received 2.16 points in identifying the need or problem, developing possible solutions, and constructing a prototype steps, 2.00 points for selecting the best possible solution, testing and evaluating the solution, and communicating the solution steps. Compared to Activity 1, there was an increase in students' scores, especially in constructing a prototype step.

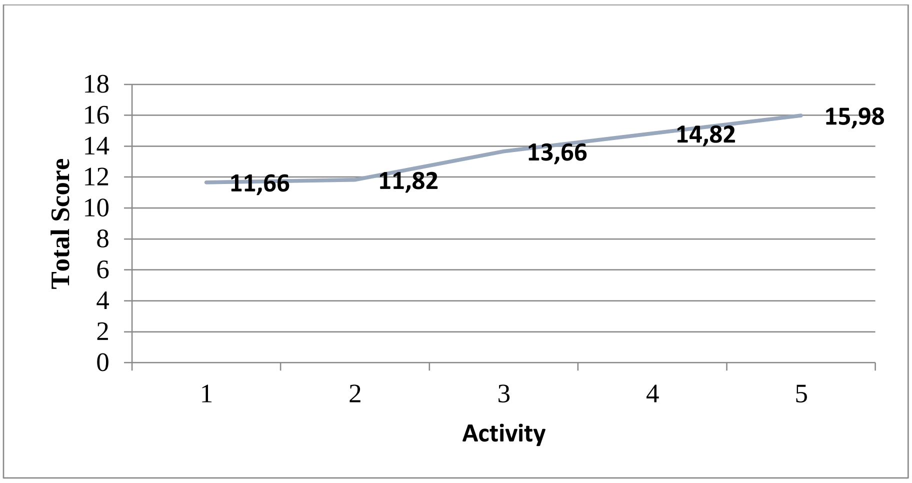
In the let there be no unheated homes activity (Activity 3), students received 2.50 points in selecting the best possible solution and communicating the solution steps, 2.33 points in identifying the problem and testing and evaluating the solution steps, 2.00 points in developing possible solutions and constructing a prototype steps. Though students performed at target in Activity 3's developing possible solutions and constructing a prototype steps, a decrease was observed in these steps' scores compared to the first two activities.

In the struggle against cold weather conditions activity (Activity 4), students received 2.83 points in communicating the solution step, 2.66 points in testing and evaluating the solution step, 2.50 points in identifying the need or problem and selecting the best solution steps, 2.33 points in developing possible solutions step and 2.00 points in constructing a prototype step. In the lemon carrying containers activity (Activity 5), which was the last activity, students received 2.83 points in selecting the best solution, constructing a prototype, and communicating the solution steps, 2.66 points in testing and evaluating the solution step, 2.50 points in developing possible solutions step and 2.33 points in identifying the need or problem step. Considering the performances of students in the engineering design process steps in the five activities, constructing a prototype step saw the highest score increase.

When the average scores obtained in the activities are compared, it is found that in the thermometer activity, which was the first activity, the scores obtained through the engineering design process rubric were lower than those in the lemon carrying containers activity, which was the last activity. The distribution of study groups' average scores for steps of the design process per activity is presented in Figure 6.

Figure 6

The Distribution of Groups' Average Scores for Steps of the Design Process Per Activity



As seen in Figure 6, it was found that the total score of groups for engineering design process steps was 11.66 points, while this was 11.82 points for the anti-freezing milk tank activity, 13.66 points for the let there be no unheated homes activity, 14.82 points for the struggle against cold weather conditions activity and 15.98 points for the lemon carrying containers activity. In line with this, it can be said that during engineering design-based activities, students' design skills improved.

Discussion, Conclusion, and Recommendations

This study aimed to examine the impact of engineering design-based activities on students' problem-solving skills and the changes in students' design skills during the activities. Five engineering design-based activities were performed within the sixth-grade Matter and Heat unit. The study found that there was a statistically significant score difference between PsST pre-test and post-test scores ($\overline{X}_{\text{pre-test}}$=33.17, $\overline{X}_{\text{post-test}}$=37.04), obtained to examine the impact of the activities on students' problem-solving skills. In line with the findings of the study, it was concluded that engineering design-based activities performed in the context of students' real-world contribute to the improvement of students' problem-solving skills. Similar to the results of this study, Pekbay (2017) found that STEM activities are effective in improving seventh-grade students' real-world-based problem-solving skills. Similarly, in the literature, many applied studies found that STEM activities performed with students from different grades contributed to their problem-solving skills (Ceylan, 2014; Dewaters & Powers, 2006; Lin et al., 2015; Mauch, 2001; Sahin et al., 2015).

In this study, the engineering design process developed by Hynes et al. (2011) was followed and it was determined that the problem-solving skills of the students enhanced. Syukri et al. (2018) noted that activities integrated with the five steps of the engineering design process (ask, imagine, plan, create, improve) help improve the problem-solving skills of students in scientific problems. Well-planned, systematically developed engineering design tasks provide context for the development of students’ problem-solving skills (Roehrig et al., 2012; Syukri et al., 2018). Unlike this research, Özçelik & Akgündüz (2018) carried out STEM activities as extra-curricular, and they found that extra-curricular STEM practices performed out of school developed the problem-solving skills of gifted middle school students.

Considering the results on the impact of group activities performed as part of the study, it was found that students' average scores for identifying the problem step of the engineering design process were at target in the first four activities ($\bar{X}$=2.16, $\bar{X}$=2.16, $\bar{X}$=2.33, $\bar{X}$=2.33, respectively), and above target in the fifth activity ($\bar{X}$=2.50). Thus, the scores students received for identifying the problem step of the engineering design process increased as the study progressed. In the literature, many applied studies also found that design-based activities performed with students from different grades and prospective teachers improved individuals' skills of identifying the need or problem (Bergin et al., 2007; Bozkurt, 2014; Cardella et al., 2002; Dym et al., 2002; Ercan, 2014). The fact that the problems in the activities were those that were or could be experienced in a real-world setting and were placed in the context of Guzelyurt in Aksaray, where students live, may have contributed to the increase of scores during the activities. Using problems situated in a real-world context is important in the process of developing engineering design-based activities (NAE & NRC, 2009) and students' encountering problems situated in a real-world context has helped them internalize the problems and become more eager to solve them (English et al., 2017).

Considering students' scores for developing possible solutions step of the engineering design process, it was found that students' scores were at target in the first and third activities ($\bar{X}$=2.00), the second ($\bar{X}$=2.16), and the third activity ($\bar{X}$=2.33) and above target in the fifth activity ($\bar{X}$=2.50). In line with this, it can be said that students' skills relating to developing possible solutions step improved, which is one of the steps where creativity is used to the highest degree to tackle the complex structures of problems that are or can be encountered in a real-world settings (Brunsell, 2012; Hynes et al., 2011; Wendell, 2008). In the literature, many studies concluded that activities performed with students from different grades, prospective teachers, and teachers have capabilities of improving individuals' skills for developing possible solutions, and the participants' skills improved (Bozkurt, 2014; Capobianco, 2011; Ercan, 2014; Hacıoğlu, 2017). In selecting the best possible solution step, it was found that the average scores were at target in the first and second activities ($\bar{X}$=2.00) and above target in the third ($\bar{X}$=2.50), the fourth ($\bar{X}$=2.50), and the fifth activities ($\bar{X}$=2.83). At this step, study groups partially analyzed the strong and weak aspects of the possible solutions they developed and selected the best solution by partially considering the criteria and constraints relating to the problem. It was found that as the engineering design-based activities were performed, students better analyzed the strong and weak aspects of the possible solutions they developed. The fact that students compromised less in the first activities than in the last activities on criteria and constraints gives rise to the thought that they may have experienced problems when it came to selecting the best solution. Regarding selecting the best solution step of the engineering design process, in a study to determine the impact of design-based science education activities on seventh-grade students' engineering capabilities, Ercan (2014) found that students' capabilities of selecting the best solution improved during the activities. Similarly, Bozkurt (2014) found that engineering design-based science education performed with prospective teachers improved individuals' capabilities of selecting the best solution.

Considering students' scores for constructing a prototype step, it was found that students' scores were below target in the first activity ($\bar{X}$=1.50), at target in the second ($\bar{X}$=2.16), third ($\bar{X}$=2.00), and fourth activities ($\bar{X}$=2.00), and above target in the fifth activity ($\bar{X}$=2.83). It was found that the average scores, which were below target in the first activity, became at target and above target as the engineering design-based activities were performed. It was concluded that study groups used the necessary materials and constructed their prototypes to meet the criteria of the task in line with the best solution they selected for solving the problem and their drawings. However, it was observed that prototypes constructed in the first activity met the task's criteria on a limited scale. It is thought that this was due to the study groups' ignoring some criteria. Regarding constructing a prototype step of the engineering design process, in a study to determine the impact of design-based science education activities on seventh-grade students' engineering capabilities, Ercan (2014) found that students' capabilities of constructing a prototype improved during the activities. Similarly, in a study to examine the impact of STEM education-based activities on prospective science teachers' creative thinking skills, Hacıoğlu (2017) found that prospective teachers' skills of constructing a prototype improved after the activities.

In testing and evaluating the solution(s) step, students' average scores were at target in the first ($\overline{X}$=2.00), second ($\overline{X}$=2.00) and third activities ($\overline{X}$=2.33), and above target in the fourth and fifth activities ($\overline{X}$=2.66). It was found that the average scores, which were at target in the first activities, became above target as the engineering design-based activities were performed. It was concluded that study groups' tested the prototypes they constructed and correctly recorded the data they obtained. These data reflect the performance of the prototype, such as whether it serves its purpose and what its strong and weak aspects are. Testing and evaluating the solution(s) is crucial for student groups to revise their designs for solving problems. Moreover, it is believed that students' testing and evaluating prototypes also helps improve the development of their critical thinking skills. Similarly, in the literature, many applied studies also found that design-based activities performed with students and prospective teachers improved individuals' capabilities of testing and evaluating the solution(s) (Bozkurt, 2014; Ercan, 2014; Hacıoğlu, 2017).

In communicating the solution step, it was found that students were at target in the first and second activities ($\overline{X}$=2.00) and above target in the third ($\overline{X}$=2.50), fourth and fifth activities ($\overline{X}$=2.83). In line with the obtained data, it was concluded that study groups reported test results and communicated how the solution would be developed. At this step, students defended the performance of the design they built against other study groups and presented their products. As the process progressed, study groups communicated their designs' performances better. It is thought that these data are related to the development of students' self-expression. Similarly, Ercan (2014) indicated that activities performed with students improved students' capabilities in communicating the solution step of the engineering design process.

Groups' scores for the steps of the engineering design process showed decreases and increases from one activity to the other, but the total scores increased from the first to the last activity (11.66, 11.82, 13.66, 14.82, 15.98, respectively). In line with this, it can be said that during engineering design-based activities, students' design skills improve. Similarly, in the literature, many applied studies also found that design-based activities performed with students from different grades and prospective teachers improved individuals' capabilities in engineering design process steps (Bergin et al., 2007; Bozkurt, 2014; Cardella et al., 2002; Dym et al., 2002; Ercan, 2014). Chiang et al (2020) found that in interdisciplinary STEM courses in second- and fourth-grade students’ engineering design skills significantly developed. However, there was no significant difference in the skills of sixth-grade students. The reason for this might be that the students may have failed to arrive at a comprehensive understanding of the learning themes of these activities. It has been emphasized that virtual or physical modeling of the prototype in engineering design-based activities is effective in developing students’ problem identification and analysis skills (Fan & Yu, 2017). Therefore, the results of this study concur with the literature.

The following suggestions can be made based on the findings of this study:

- Engineering design-based activities can be realized using simple materials to allow students to find solutions to problems they encounter in their contexts.
- It is recommended that students create a prototype with the real materials before constructing the product and proceed with the next step after receiving feedback from their teachers about their prototype.

- Schools in rural areas can prepare booklets containing engineering design-based activities, similar to the ones developed in this study, that fit the context of the school and organize activities cooperatively with nearby schools.
- This study focused on students' design and problem-solving skills. Future research may investigate the impact of engineering design-based activities on other 21st-century skills of students.
- The engineering design-based activities performed in the study are limited to the context of the district of Guzelyurt, Aksaray. By widening the context, these activities might be made more common across the country.
- Designs and processes resulting from engineering design-based activities can be exhibited in a regional science festival to be organized.
- The impact of engineering design-based activities on problem-solving and designing skills can be investigated with long-term follow-up studies.

References

Akarsu, M., Okur Akçay, N., & Elmas, R. (2020). STEM eğitimi yaklaşımının özellikleri ve değerlendirilmesi [Characteristics and evaluation of STEM education approach]. *Bogazici Journal of Education, 37*(Special Issue), 156-175.

Alfiana, R., Parno, P., & Yogihati, C.I. (2021). Development of ILAU based on PBL-STEM model with formative assessment as an opportunity to improve problem solving skills in heat and temperature topics. *Journal of Physics: Conference Series, 1747*, doi:10.1088/1742-6596/1747/1/012005.

Althouse, L. A., Ware, W. B., & Ferron, J. M. (1998, April). *Detecting departures from normality: A monte carlo simulation of a new omnibus test based on moments*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, CA.

Baran, E., Canbazoglu-Bilici, S., Mesutoglu, C., & Ocak, C. (2019). Investigating the impact of an out-of-school STEM education program on students' attitudes towards STEM and STEM careers. *School Science and Mathematics,119*(4), 223-235.

Battelle for Kids (2019). *Framework for 21st century learning definitions*. http://static.battelleforkids.org/documents/p21/P21_Framework_DefinitionsBFK.pdf.

Bergin, D., Khanna, S. K., & Lynch, J. (2007). Infusing design into the G7–12 curriculum: two example cases. *International Journal of Engineering Education, 23*(1), 43-49.

Bozkurt, E. (2014). *Mühendislik tasarım temelli fen eğitiminin fen bilgisi öğretmen adaylarının karar verme becerisi, bilimsel süreç becerileri ve sürece yönelik algılarına etkisi [The effect of engineering design based science instruction on science teacher candidates' decision making skills, science process skills and perceptions about the process* [Unpublished doctoral dissertation]. Gazi University, Ankara.

Bozkurt Altan, E. (2018). Tasarım temelli fen eğitimi ve problem dayalı STEM uygulamaları [Design based science education and problem based STEM practices]. In S. Çepni (Ed.), *Kuramdan uygulamaya STEM$_{+E}^{+A}$ eğitimi [STEM$_{+E}^{+A}$ education from theory to practice]* (pp.169-203). Pegem Akademi.

Brunsell, E. (2012). The engineering design process. In E. Brunsell (Ed.) *Integrating engineering + science in your classroom* (pp.3-5). National Science Teacher Association [NSTA] Press.

Capobianco, B. M. (2011). Exploring a science teachers uncertainty with integrating engineering design: an action research study. *Journal of Science Teacher Education, 22,* 645–660.

Cardella, M. E., Atman, C. J., Adams R. S., & Turns, J. (2002). *Engineering student design processes: Looking at evaluation practices across problems.* Annual American Society of Engineering Education Conference, Montreal, Canada.

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

Chiang, F-K., Chang, C-H., Wang, S., Cai, R-H., & Li, L. (2020). The effect of an interdisciplinary STEM course on children's attitudes of learning and engineering design skills. *International Journal of Technology and Design Education,* https://doi.org/10.1007/s10798-020-09603-z

Demir, S. (2015). Perception of scientific creativity and self-evaluation among science teacher candidates. *Journal of Education and Practice, 6*(18), 181-183.

Dewaters, J., & Powers, S. (2006, July). *Improving science literacy through project- based K-12 outreach efforts that use energy and environmental themes*. Proceedings of the 113th Annual ASEE Conference & Exposition, Chicago, IL.

Dym, C.L., Wood, W.H., & Scott, M. J. (2002). Rank ordering engineering designs: pairwise comparison charts and borda counts. *Research in Engineering Design, 13*, 236-242.

Elliott, A., & Woodward, W. (2007). *Statistical analysis quick reference guidebook: With SPPS examples*. Sage.

Elmalı, Ş., & Balkan Kıyıcı, F. (2017). Türkiye'de yayınlanmış FeTeMM eğitimi ile ilgili çalışmaların incelenmesi [Review of studies published in Turkey]. *Sakarya University Journal of Education, 7*(3), 684-696.

English, L. D., King, D., & Smeed, J. (2017). Advancing integrated STEM learning through engineering design: Sixth-grade students'design and construction of earthquake resistant buildings. *The Journal of Educational Research, 110*(3), 255-271.

Ercan, S. (2014). *Fen eğitiminde mühendislik uygulamalarının kullanımı: Tasarım temelli fen eğitimi* [*Use of engineering applications in science education: design based science education*] [Unpublished doctoral dissertation]. Marmara University, İstanbul.

Ernst, J. V., & Haynie, W. J. (2010). Curriculum research in technology education. In P. Reed ve J. LaPorte (Eds.), *Research in technology education. Council on Technology Teacher Education, 59th Yearbook* (pp. 192-217). Ball State University.

Fan, S-C., & Yu, K-C. (2017). How an integrative STEM curriculum can benefit students engineering design practices. *International Journal of Technology and Design Education, 27,* 107-129.

Felix, A. (2016). *Design based science and higher order thinking* [Unpublished doctoral dissertation]. Virginia Polytechnic Institute and State University, Virginia.

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

Hynes, M., Portsmore, M., Dare, E., Milto, E., Rogers, C., & Hammer. D. (2011). Infusing engineering design into high school STEM cources. *Publications,* Paper 165. https://digitalcommons.usu.edu/ncete_publications/165.

Jolly, A. (2014). Six characteristics of a great STEM lesson. *Education Week*. https://www.edweek.org/teaching-learning/opinion-six-characteristics-of-a-great-stem-lesson/2014/06.

Kan, A. (2009). Ölçme sonuçları üzerinde istatistiksel işlemler [Statistical operations on measurement results]. H. Atılgan (Ed.), *Eğitimde ölçme ve değerlendirme [Assessment and Evaluation in Education]* (pp. 397–456). Anı Yayıncılık.

Le Thi Thu ,H., Tran,T., Trinh Thi Phuong, T., Le Thi Tuyet, T., Le Huy, H., & Vu Thi, T. (2021). Two decades of STEM education research in middle school: A bibliometrics analysis in Scopus database (2000–2020). *Education Sciences, 11*(353), 1-15. https://doi.org/ 10.3390/educsci11070353

Lin, K. Y., Yu, K. C., Hsiao, H. S., Chu, Y. H., Chang, Y. S., & Chien, Y. H. (2015). Design of an assessment system for collaborative problem solving in STEM Education. *Journal of Computer Education, 2*(3), 301-322.

Mauch, E. (2001). Using technological innovation to improve the problem-solving skills of middle school students: Educators' experiences with the lego mindstorms robotic invention system. The Clearing House: *A Journal of Educational Strategies, Issues and Ideas, 74*(4), 211-213.

Miaoulis, I. (2009). *Engineering the K-12 curriculum for technological innovation*. IEEE USA Today's Engineer.

Morgan, G.A., Leech, N.L., Gloeckner, G.W., & Barrett, K.C. (2004). *SPSS for introductory statistics: Use and interpretation* (2nd. Ed.). Psychology Press. https://doi.org/10.4324/9781410610539

Ministry of National Education [MoNE]. (2013). *İlköğretim kurumları (ilkokullar ve ortaokullar) fen bilimleri dersi (3., 4., 5., 6., 7. ve 8. sınıflar) öğretim programı* [Science course curriculum (Primary and middle school 3, 4, 5, 6, 7, and 8th grades)]. Ankara.

Ministry of National Education [MoNE]. (2017). *Fen bilimleri dersi öğretim programı (ilkokul ve ortaokul 3, 4, 5, 6, 7, ve 8. sınıflar)* [Science course curriculum (Primary and middle school 3, 4, 5, 6, 7, and 8th grades)]. Ankara.

Ministry of National Education [MoNE]. (2018). *Fen bilimleri dersi öğretim programı (ilkokul ve ortaokul 3, 4, 5, 6, 7, ve 8. sınıflar)* [Science course curriculum (Primary and middle school 3, 4, 5, 6, 7, and 8th grades)]. Ankara.

National Academy of Engineering [NAE] & National Research Council [NRC] (2009). *Engineering in K-12 education understanding the status and improving the prospects.* L. Katehi, G.Pearson, & M. Feder (Eds.). National Academies Press.

National Academy of Engineering [NAE] (2010). *Standards for k-12 engineering education?*. National Academies Press.

National Aeronautics and Space Administration [NASA] (2015). *Let it glide: Facilitation guide.* https://www.nasa.gov/sites/default/files/files/EDC02_Let_It_Glide_Facilitation_Guide_FINAL.pdf

National Assessment Governing Board [NAGB] (2010). *Technology and engineering literacy framework for the 2014 national assessment of educational progress* (Pre-Publication Edition). San Francisco.

National Research Council [NRC] (2009). *Learning science in informal environments: People, places, and pursuits*. http://www.nap.edu/catalog.php?record_ id=12190.

National Research Council [NRC] (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* The National Academic Press.

Özçelik, A., & Akgündüz, D. (2018). Üstün/özel yetenekli öğrencilerle yapılan okul dışı STEM eğitiminin değerlendirilmesi [Gifted/talented students' out-of-school STEM education]. *Trakya University Journal of Education Faculty, 8*(2), 334-351.

Özer, İ. (2019). *6. sınıf kuvvet ve hareket ünitesinde gerçekleştirilen Algodoo temelli etkinliklerin öğrencilerin tasarım becerilerine ve akademik başarılarına etkisi [Evaluation of the impact of engineering design-based activities through algodoo performed in 6th-grade "force and motion" unit on design skills and academic achievement of the students* [Unpublished masters's thesis]. Aksaray University, Aksaray.

Özer, E. İ., & Canbazoğlu Bilici, S. (2021). Mühendislik tasarım temelli Algodoo Etkinliklerinin Öğrencilerin tasarım becerilerine ve akademik başarılarına etkisi [The effect of engineering design-based Algodoo activities on students' design skills and academic achievement]. *Hacettepe University Journal of Education, 36*(2), 301-316.

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

Petroski, H. (1996). *Invention by design: How engineers get from thought to thing.* Harvard University Press.

Razali, N.M., & Wah, Y. B. (2011). Comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling tests. *Journal of Statistical Modeling and Analytics, 2*(1), 21-33.

Roehrig, G. H., Moore, T. J., Wang, H.H., Park, M.S. (2012). Is adding the E enough? Investigating the impact of K-12 engineering standards on the implementation of STEM integration. *School Science and Mathematics, 112*(1), 31-44.

Sahin, A., Gulacar, O., & Stuessy, C. (2015). High school students‟ perceptions of the effects of science Olympiad on their STEM career aspirations and 21st century skill development. *Research in Science Education, 45*(6), 785-805. https://doi.org/10.1007/s11165-014-9439-5

Sarı, U., Duygu, E., Şen, Ö.F., & Kırındı, T. (2020). The effect of STEM education on scientific process skills and STEM awareness in simulation based inquiry learning environment. *Journal of Turkish Science Education, 17*(3), 387-405.

Sarıkaya, S. (2020). *Ortaokul öğrencilerinin ısı ve sıcaklık konusundaki kavram yanılgılarının belirlenmesi ve giderilmesi [Determine and eliminate the misconceptions about heat and temperature of secondary school students]* [Unpublished masters's thesis]. Mersin University, Mersin.

Suratno, Wahono, B., Chang, C-Y., Retnowati, A., & Yushardi. (2020) Exploring a direct relationship between students' problem-solving abilities and academic achievement: A STEM education at a coffee plantati on area. *Journal of Turkish Science Education, 17*(2), 211-224.

Syukri, M., Soewarno, S., Halim, L., & Mohtar, L.E. (2018). The impact of engineering design process in teaching and learning to enhance students' science problem-solving skills. *Jurnal Pendidikan IPA Indonesia, 7*(1), 66-75.

Usta, N., Yılmaz, M. (2020). Impact of the KWL reading strategy on mathematical problem-solving achievement of primary school 4th graders, *The Journal of Educational Research,* 113(5), 343-363.

Ünlü, Z. K., & Dökme, I. (2016). Özel yetenekli öğrencilerin FeTeMM'in mühendisliği hakkındaki imajları [Images of gifted students about STEM engineering]. *Trakya University Journal of Education Faculty, 7*(1), 196-204.

Wang, H. (2012). *A new era of science education: Science teachers„ perceptions and classroom practices of science, technology, engineering, and mathematics (STEM) integration*. University of Minnesota.

Wells, J. G. (2008). *STEM education: The potential of technology education*. Proceedings from 95th Annual Mississippi Valley Technology Teacher Education Conference, Mississippi.

Wendell, K. B. (2008). *The theoretical and empirical basis for design-based science instruction for children.* [Unpublished Qualifying Paper]. Tufts University.

Yıldırım. B., & Türk, C. (2018). STEM uygulamalarının kız öğrencilerin STEM tutum ve mühendislik algılarına etkisi [The effect of STEM applications on girls' STEM attitude and engineering perception]. *Adıyaman University, Journal of Social Sciences,10* (30), 842-884.

Yılmazel, A. (2019). *Ortaokul öğrencilerinin ısı ve sıcaklık konusundaki kavram yanılgılarını gidermede problem dayalı öğrenme yönteminin etkisi [The effect of the problem-based learning method in eliminating the misconception of heat and temperature of secondary school students]* [Unpublished masters's thesis]. Mersin University, Mersin.

Appendix

Learning Objectives related to Activities

Disciplinary	The learning objectives	Activity*
Science	• Classifies materials in terms of thermal conductivity.	All activities
	• Discusses the importance of thermal insulation in buildings in terms of the domestic and national economy, and effective use of resources.	Activity 3, Activity 4
	• Determines the selection criteria of thermal insulation materials used in buildings.	Activity 3, Activity 4
	• Develops alternative thermal insulation materials.	Activity 2, Activity 3, Activity 4, E Activity 5
Technology	• Recognizes the interface and features of the spreadsheet program and creates a table.	All activities
	• Able to format the table for a specific purpose.	All activities
	• Performs calculations with created table.	All activities
	• Visualizes data using appropriate chart types.	All activities
	• Develops an algorithm for solving the problem.	All activities
	• Tests the solution of an algorithm.	All activities
Engineering	• Defines a real-world problem.	All activities
	• Generates possible solutions for the problem and selects the appropriate one within the criteria.	All activities
	• Designs and presents the product.	All activities
	• Develops strategies to market and promote the product.	All activities
Mathematics	• Solves problems that require four operations with natural numbers.	All activities
	• Divides a natural number by a fraction and a fraction by a natural number. Explains the meaning of the operation.	Activity 3, Activity 4
	• Uses ratios to compare quantities and displays the ratio in different formats.	Activity 3, Activity 4
	• In cases where a whole is divided into 2 parts, it determines the ratio of two parts to each other or each part to the whole. In problems, given one of the ratios, finds the other.	Activity 3, Activity 4
	• Recognizes area measurement units.	Activity 3, Activity 4
	• Solves area problems.	Activity 3, Activity 4
	• Calculates and interprets the arithmetic mean of a data group.	All activities
	• Uses arithmetic mean to compare and interpret data.	All activities

Note. *Activity 1- Thermometer, Activity 2- Anti-freezing milk tank, Activity 3- Let there be no unheated home, Activity 4- Struggle against cold weather conditions, Activity 5- Lemon Carrying Containers.