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The effect of problem-based stem activities on students' achievement and attitudes towards engineering

Gamze Kırılmazkaya[a1], Harran University, Şanlıurfa-Mardin Highway, 18th km. Şanlıurfa, Turkiye, gamzekirilmazkaya@gmail.com

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Abstract

This study aimed to examine the effect of STEM activities prepared according to the problem-based learning approach on students' academic achievement and attitudes toward engineering. A one-group pretest-posttest experimental model, one of the quantitative research methods, was used in the study. In the study, the achievement test was used to reveal students' knowledge levels about the definition of water and the importance of water, the physical, chemical, and biological properties of water, the water cycle, water pollution, and water treatment. Another data collection tool used in the study was the Engineering Attitude Scale. According to the findings obtained from the research, it was concluded that problem-based STEM activities had a positive effect on student's academic achievement but did not make a significant difference in engineering attitudes. The findings of the study were discussed and various suggestions were made for future studies.

Keywords: Attitude; engineering design process; problem-based STEM; STEM; water

* ADDRESS FOR CORRESPONDENCE: Gamze Kırılmazkaya, Harran University, Şanlıurfa-Mardin Highway, 18th km. Şanlıurfa, Turkiye,
E-mail address: gamzekirilmazkaya@gmail.com

1. INTRODUCTION

STEM education, which is the abbreviation of Science, Technology, Mathematics, and Engineering disciplines, has emerged as an interdisciplinary education approach with the need for individuals who will contribute to the shaping of cultural and economic development with an innovative, creative, and problem-solving perspective due to the increasing competition, political, economic, health and industrial reasons in developing countries in the globalizing world. One of the aims of the Science Curriculum is to raise science-literate individuals. In the 21st century, the need for inquisitive, productive, and creative individuals in the fields of Science, Technology, Engineering, and Mathematics is increasing day by day.

The basis of raising individuals with the aforementioned skills is to improve the education system, students, and teachers. Therefore, teachers who attach importance to STEM education are needed. According to Weber (2011), STEM activities are effective in increasing students' knowledge and interest in STEM fields. In particular, he argues that STEM education can increase students' achievement and motivation with subjects that include real-world problems. STEM education can be provided through alternative learning methods such as project-based learning, inquiry-based learning, and problem-based learning.

According to Rehmat (2015), problem-based learning is one of the ways to realize STEM education and develop high-level thinking skills. STEM education practices generally start with a problem and engineering design process steps are used to find a solution to the problem. These steps are: asking, imagining, planning, designing, and developing. The foundation of STEM education is the field of engineering. Therefore, it can be stated that engineering education is particularly important in terms of the STEM education approach (Ercan, 2014). Engineering education can be provided by integrating the field of engineering into science, technology, and mathematics with appropriate activities (NRC, 2010).

The problem-based learning approach is a student-centered approach in which students access information on real-life problem situations through collaboration and problem-solving (Hmelo-Silver, 2004; Carlos et al., 2023). Problem-based learning is a teaching method that supports lifelong learning in which students are active in the process of structuring knowledge, taking into account their prior knowledge, conducting both group and individual research to solve real-life problems, and using effective communication skills (Hmelo-Silver, 2004; Kanyesigye et al., 2023). Barrows (2002) defined problem-based learning, which shows a holistic approach to education, as having the potential to replace traditional lecture-based teaching to develop students' conceptual knowledge and higher-order thinking skills. In problem-based learning, students apply what they have acquired through self-regulated learning to new problems they encounter and reflect on what they have learned in the process of solving the problem (Tüysüz et al., 2010).

Among the aims of problem-based learning; students' knowledge acquisition skills, their ability to transfer the knowledge they have acquired, and gaining effective problem-solving skills are included. In addition, problem-based learning allows individuals to develop self-learning skills and intrinsic motivation (Hmelo-Silver, 2004; Wijnia et al., 2024). Problem-based learning is suitable for engineering and other STEM disciplines as it enables students to develop problem-solving skills and confidence. STEM starts with the presentation of a real-life problem and ends with finding and testing several solutions to the problem by following and repeating the steps of the engineering design process and determining the most appropriate solution (Moore et al., 2014).

The models that students develop for problem-solving, and constructive and creative activities involving qualitative or quantitative relationships enable students to address the problem with an interdisciplinary approach (Smith, 2012). Problem-based learning is suitable for engineering and other STEM disciplines as it enables students to develop their skills and self-confidence in solving problems they have never seen before (Doppelt et al., 2008; Sadler et al., 2014). When problem-based learning is provided to students in the engineering design process integrated with STEM application, interdisciplinary learning is provided that can increase domain knowledge (Hmelo-Silver, 2004). The engineering design process is one of the teaching methods used in STEM education (Brophy et al., 2008). While creating their designs in the engineering design process, students can express a problem they encounter in daily life in more than one way or produce more than one solution to that problem (Bayar & Taş 2024).

In the engineering design process, students can both develop their engineering skills and better understand and learn the relationship between science and technology (Kolodner, 2002). Wendell and Kolodner (2014) stated that engineering design offers students unique opportunities to develop ideas and learn disciplinary practices. At a theoretical level, engineering practices offer students unique opportunities. The engineering design process consists of the steps of asking, imagining, planning, designing, and improving (EIE, 2013). The asking step consists of asking the right questions about the solution of the problem, defining the problem, and identifying the limitations of the solution. The imagining step involves brainstorming about the solution where students need to find possible solutions to the problem. In the planning step, students evaluate the ideas generated and choose the best method. Then, diagrams related to the method are drawn and necessary materials are prepared. In the design phase, the plan is implemented and the design is created. The design is then tested. In the improvement step, the tested and created designs are tried to be further improved and the missing parts of the designs are completed (Çavaş et al., 2013).

The most important step towards STEM integration in Turkey started in 2017 with the addition of the "Science and Engineering Applications" unit and "Engineering and Design Skills" for the engineering component of STEM education in the Science Curriculum (MONE, 2017). In the 2018 curriculum, "Science, Engineering and Entrepreneurship Practices" were included in all units (MONE, 2018). One of the general aims of the science curriculum is to develop career awareness and entrepreneurship skills related to science (MONE, 2017; MONE, 2018). Students' interest in STEM fields is an important factor that determines their future career choices. Research has shown that students choosing a profession in STEM and continuing their university education in this direction depends on their STEM career interests (Maltese & Tai, 2011).

Water, one of the basic elements of the environment, is very important not only for living things but also for the continuity of all life on earth. In addition, water takes place in human life with its features such as drinking, sheltering, cleaning, traveling on it, and using it in agricultural activities. The depletion of water resources has become a concern of almost every country in the world. Increasing global water consumption, much more than the increase in human population, is leading to a lack of safe drinking water. The main sources of drinking water are surface water, groundwater and groundwater directly influenced by surface water such as shallow wells. Surface water, which is initially formed by rain or snowfall, is usually easy to find and is not mineralized by the earth's crust, has the disadvantages of being easily accessible but also of being easily contaminated by microorganisms and chemical impurities. For this reason, it is important to educate people from a young age about the effective use of water and water conservation.

Raising awareness of students about water resources, saving water, protecting the diminishing clean water resources ensuring the conscious use of water, increasing the level of knowledge of secondary school students about water, and transferring water awareness to students should be ensured. Archie (2003) stated that when students learn environmental education through a problem-based learning approach, they tend to understand better, retain longer, and take responsibility for their learning.

1.1. Purpose of study

In this study, we focused on the effect of problem-based STEM education on students' understanding of water and its properties in the Structure and Properties of Matter unit and their engineering attitudes. In the study, middle school students were asked to solve a problem situation related to water pollution using the engineering design process. The Research questions are as follows:

1. What is the effect of problem-based STEM activities on middle school students' understanding of water and its properties?

2. What is the effect of problem-based STEM activities on middle school students' attitudes towards engineering?

2. METHODS AND MATERIALS

In this study, a one-group pretest-posttest weak experimental design was used. Weak experimental designs without randomization and group matching are a type of quasi-experimental research that examines whether there is a significant difference in the behaviors of the participants depending on time by taking measurements of the dependent variable before and after an experimental procedure (Büyüköztürk, 2011).

Table 1.
Process of the study

Group	Pre-tests	Process	Post-tests
Single group	Achievement test Engineering attitude	Problem-based STEM 2.	Achievement test Engineering attitude

In this research model, the study group is first given pre-test measurements, then the experimental procedure is applied and finally, post-tests are applied (Table 1).

2.1. Participants

The study group was selected through purposive sampling. The participants were 13 middle school students, 10 girls and 3 boys, from a rural area in the southeastern part of Turkey, who were studying in a public school where transportation education was implemented. The ages of the participants ranged between 12-13 years. The participants were divided into three groups. Groups of three and one group of four. Small groups of participants were encouraged so that participants are motivated through peer interaction that builds relationships to hold each other accountable. The school where the research was conducted is located in a region with low economic income levels. There has not been any previous implementation within the scope of STEM education at the school.

2.2. Data collection instrument

Within the scope of the study, data collection tools consisting of achievement tests and engineering attitude scales were used. In the study, the achievement test developed by Özcan (2019) was applied to reveal the students' knowledge levels about the definition of water and the importance of water, the physical, chemical, and biological properties of water, water cycle, water pollution, and water treatment. The multiple-choice achievement test was prepared with 5 options and was evaluated by giving "1" points for correct answers and "0" points for incorrect and blank answers. In the reliability study of the scale conducted by the researcher, the KR-20 test result was found to be 0.78. In this study, the Engineering Attitude Scale was used to determine the effect of problem-based learning supported by STEM activities on middle school students' attitudes toward engineering. The scale was developed by Engineering is Elementary (EIE, 2018) Project and adapted into Turkish by Pekmez et al., (2018). The Engineering Attitude Scale is a 5-point Likert-type scale consisting of "Strongly disagree, strongly disagree, not sure, somewhat agree, strongly agree". As a result of the validity and reliability studies of the scale, Cronbach's alpha value is .79 (Bilir, 2019).

2.3. Procedure

In the first week of the study, achievement tests and engineering attitude scales were applied as pretests to determine the cognitive levels and affective skills of the students. After the pretests were applied, STEM Education and Engineering Design Process (EDS) steps were mentioned to the students. The students in the study had never taught a lesson with STEM activities before. For them to get used to STEM activities, which they encountered for the first time in this application, car-making from plastic bottles and bridge activities from straws were carried out using engineering design steps, thus introducing students to STEM education. First of all, students were asked to form groups of three and each group was asked to assign a group name. A set of materials were provided per group for the activities to create a suitable environment for implementation. The 1st practice activity was bridge building. In this activity, students designed bridges with the materials given to them. After the bridges they designed, a competition was organized and the most durable bridge was selected. The 2nd practice activity was making a car out of a plastic bottle. At the end of the activity, a competition was organized and the group that made the car that went the farthest was chosen as the first. Thus, engineering steps were taught to students in a competitive environment. The activities were designed to engage students and spark their interest in the lesson. Then, in the "Structure and Properties of Matter" unit, "Acquires sensitivity to chemicals that pollute water, air and soil. Investigate how to remove hardness in water. Realizes by researching that the germicidal effect of chlorine is used in the treatment of water".

Activities were carried out in line with the gains. Water and the importance of water, the state of water in the world and Turkey, the properties of water, the water cycle, water pollution, the properties of potable water, and water treatment systems were covered. Related videos were shown to the students using the Education Information Network (EBA). A scenario involving a real-life problem was given to the students. Based on the scenario, students discussed in groups and tried to determine the problem situation. “Let's design a water filter, how clean is the water?” The activity was conducted. This activity aimed to get students to work together in groups and design a water filtering device from common household materials to mechanically filter dirty water and use engineering design skills. For this, students were asked to use a variety of filtering materials such as rocks, sand, charcoal, pebbles, gravel, paper towels, coffee filters, and cotton balls.

First, the students made contaminated water samples with various materials. Students first discussed the pollutants in the water samples by sight and smell. Then, the groups were introduced to the instruments that measure pH, conductivity probe soil moisture sensor, conductivity probe soil moisture sensor, CO2 gas sensor, and O2 gas sensor) and tried to determine the drinkability and properties of different water samples they brought to the classroom environment. At the end of the application, each group tested their designs by passing the dirty water through the filters (for a maximum of 90 seconds) and seeing how clean it looked (color and texture) when it came out of the funnel at the other end. The results obtained by all groups were compared and students were asked to continue the discussion in their lab reports. The groups observed what happened during the filtration process and recorded it on the evaluation worksheet. They presented their results to the class. In the last stage, the groups thought about how they could improve their filter systems (water treatment) and planned and explained their solutions (water treatment designs). Which water containers are safe to drink and why? A whole class discussion was held to answer the question. Plans can be changed after the feedback from the presentation phase. "Do you drink water from a lake or a river? Why or why not? List some words that describe good drinking water". At the end of the activity "Let's design a water filter, how clean is the water?", the group that made the cleanest water was selected first. After the applications, the achievement test and engineering attitude scale were applied as post-tests.

2.4. Data analysis

The SPSS statistical package program was used to analyze the quantitative data obtained in this study. In the literature, the kurtosis and skewness values of the variables between +1.5 and 1.5 (Tabachnick & Fidell, 2013), +2.0 and -2.0 (George & Mallery, 2010) are accepted as normal distribution.

Table 2
Descriptive analysis results

	N	Min.	Max.	M	sd	Skewness	Kurtosis
Achievement pre-test	13	7.1	57.1	26.3	14.9	.606	-.17
Achievement post-test	13	42.8	85.7	63.1	13.6	.342	-.75
Attitudes pretest	13	45.0	74.0	66.8	8.05	-1.87	4.03
Attitudes post-test	13	52.0	76.0	68.9	6.53	-1.47	2.81

When the data are analyzed, it is seen that the skewness and kurtosis coefficients of the data obtained from the achievement test are in the range of -1 and +1 (Table 2). Accordingly, it can be said that the achievement test data are normally distributed. Therefore, a Paired Sample t-test was conducted to determine whether there was a difference between the achievement test scores obtained before and after the application. It was determined that the total scores of the students from the engineering attitude scale in the pre-and post-tests did not show normal distribution (Table 2). The data were analyzed using the Wilcoxon signed-ranks test, which is one of the non-parametric statistical methods for non-normally distributed measurements (Baştürk, 2011).

3. RESULTS

In this section, statistical analysis of the research data obtained from the scales applied as pre-post tests within the scope of the research and the results obtained are given.

3.1. Achievement test

The results of the analysis of the problem-based STEM activities on students' achievement levels on water are presented in Table 3.

Table 3
Achievement test pre-post test scores analysis results

Test	n	M	ss	df	t	p
Pretest	13	26.3	14.9	12	12.704	.00
Posttest	13	63.1	13.6			

In the study investigating the effect of problem-based STEM activities on middle school student's understanding of water and its importance, the paired sample t-test was used to analyze whether there was a significant difference between achievement test pretest and post-test scores (Table 3). When the data obtained as a result of the analysis were analyzed, the increase between the mean achievement scores of the students before the application ($M_{(pretest)}$=26.3) and after the application ($M_{(posttest)}$=63.1) was found to be significant ($t_{(12)}$ =-12.704, p<.05).

3.2. Engineering attitude scale

The results of the Wilcoxon Signed-Ranks test analysis of whether the STEM activities applied affect the attitudes of middle school students towards engineering are presented in Table 4.

Table 4

Engineering attitude scale scores analysis results

Post-pretest	N	Rank Mean	Row Total	z	p
Negative sequence	3	8.67	26.0	-1.022	.307
Positive sequence	9	5.78	52.0		
Equal	1				

There was an increase in the engineering attitude scale score of the students before the application ($M_{(pretest)}$=66.8) and an increase in the attitude score after the application ($M_{(posttest)}$ =68.9). However, according to the Wilcoxon Signed Rank test results (z=-1.022; p>0.05), there was no significant difference between the engineering attitude scale pretest and posttest (Table 4).

4. DISCUSSION

In this study, the effect of problem-based learning supported by STEM activities on middle school students' academic achievement and engineering attitudes was investigated. As a result of the study, it was determined that there was an increase in points between the pre-test and post-test scores of the student's academic achievement test on the subject of water in favor of the post-test. This result obtained from the study coincides with the studies in the literature. When the literature was examined, it was revealed that engineering design-oriented STEM applications positively affected middle school students' science achievement (Ercan & Şahin, 2015; Harwell et al., 2015; Mehalik et al., 2008; Bethke Wendell & Rogers, 2013; Yılmaz et al., 2017). Helvacı and Helvacı (2019) conducted a study with 6th-grade students and found that STEM-based environmental education improved students' attitudes and knowledge levels toward the environment. In another study, Aysu (2019) investigated the effect of problem-based learning supported by STEM activities on academic achievement and knowledge retention in 6th-grade science courses.

In the quasi-experimental study, it was concluded that STEM-supported problem-based learning applied in the experimental group increased academic achievement and knowledge retention. When the studies using problem-based learning in STEM education were examined in the literature, it was concluded that it improved students' critical thinking, collaboration, and problem-solving skills (Dischino et al., 2011; Rizki & Suprapto 2024). In another study, it was determined that problem-based learning methods were effective in providing STEM integration, developing positive attitudes toward STEM, and planning future careers (Lou et al., 2011). In a study examining the effect of problem-based learning on students' content knowledge, critical thinking, and STEM attitudes, it was found that the STEM attitudes and higher-order thinking skills of the experimental group students increased significantly compared to the control group students (Rehmat, 2015). Yıldırım and Altun (2015) concluded in their study that STEM education and engineering practices in science courses positively affected students' academic achievement. Yıldırım and Selvi (2016) examined the effects of STEM applications and whole learning on students' academic achievement, attitudes towards STEM, motivation, perceptions of inquiry learning skills, and retention of knowledge with seventh-grade students. According to the results of the study, the academic achievement scores of the experimental group students who were taught STEM applications were higher than the control group students.

Another result obtained in the study was that STEM-supported problem-based learning did not make a significant difference in students' attitudes toward engineering. When the pre-test and post-test scores were analyzed, it was observed that there was an increase in students' attitudes towards engineering. However, this increase is at a low level. Other studies have shown that engineering design-based science curriculum units can support elementary students' science content knowledge while helping students learn to design, build, and test solutions to engineering problems (Means et al., 2021). In a long-term study by Cunningham and Lachapelle in 2010 using EIE materials, significant differences were observed in students' attitudes towards engineering after the training. Studies also show that through engineering design, students develop a more positive attitude toward engineering as a career (Cunningham & Lachapelle, 2010; Kolodner, 2002; Mehalik et al., 2008).

5. CONCLUSION

The school where the study was conducted is a school in Turkey where students continue to receive transportation education. Transportation schools are schools where students with low socio-economic status in rural areas receive education. In Turkey, it is seen that students with low socioeconomic status generally tend to be teachers and doctors. Therefore, we can say that this situation is more effective on students' attitudes towards engineering. Attitude change requires a long-term effort. Since the training module used in the study lasted only 4 weeks, it is estimated that it was insufficient to change attitudes. Therefore, more comprehensive and long-term research is needed to reach meaningful conclusions in the study. However, according to this result, it can be inferred that students who used engineering design activities for the first time in the science education course could not fully perceive the purpose of the activities and their relationship with science education. It is thought that longer practices should be carried out to raise students' awareness and develop positive attitudes towards the engineering profession.

It can be concluded that these skills should be gained by using engineering design steps from early periods in regions with low socio-economic levels. In line with the findings obtained, it is thought that to increase the effectiveness of the STEM-based environmental education course, more practical activities should be carried out. More studies on STEM education can be carried out in disadvantaged schools such as regional boarding schools and village schools. Science education activities with nature should be organized for students and environmental awareness in general and awareness of the importance of water in particular can be created by ensuring that students spend quality time in nature. It is thought that school curriculum programs should be revised according to different types of STEM education. To effectively implement the prepared environmental education programs, STEM environments can be created for the learning purpose.

In addition, it is suggested that STEM activities with students should be implemented for a longer period and with activities that include more applications throughout the curriculum without time and course restrictions. STEM-based environmental education can be linked to other courses to help students understand it better. Importance should be given to the applications of STEM education with other methods and various studies can be conducted in this direction. The activities carried out in the study can lead students to gain inquiry experience and use technology to solve real-life problems. Students should be encouraged to use technology in science education courses. Technology allows students to use real data to carry out inquiry tasks. This allows students to have real experience with measurements and real-time data collection. This allows students to learn through discovery.

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