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# The Effect of Educational Robotics Applications on Students' Academic Achievement and Problem-Solving Skills in Science Education

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## Abstract

The study explored the effects of robotic-assisted applications on the variables of academic achievement and problem-solving skills in the "Propagation of Light" unit of the 5th grade science course. The study employed the pretest-posttest control group design, one of the quasi-experimental methods. The study sample consist of 36 5th grade students attending a public school in Turkey located in a district center in the Western Black Sea region. The study was carried out in a six-week period in the 2019-2020 academic year, and 19 of the students were selected as the control and 16 as the experimental group. Robotic supported activities were applied to the students in the experimental group, and the activities prescribed by the Science Curriculum were applied to the students in the control group. Open-ended and closed-ended "Academic Achievement Test" and "Problem-Solving Skills Test" were used as pretest and posttest in both groups. The data were analyzed using the independent samples t-test. The study results revealed that the academic achievement and problem-solving skills of the students in the experimental group, in which robotic-assisted activities were used, were significantly higher in both tests compared to the students in the control group.

## Introduction

The term robotics was first introduced in the 1940s by the famous science-fiction writer Isaac Asimov as a branch of science dedicated to the study of robots (Usmonova, 2021). The branch of science that combines physical activity with the decision-making process and examines machines that can replace humans while performing a task is defined as robotics (Siciliano et al., 2010). However, since the late 1980s, robotics has been used in education both as a teaching subject and as an auxiliary tool in teaching various subjects such as mathematics, science, engineering, technology, and computer (Karatrantou & Panagiotakopoulos, 2011).

### Educational Robotics

Robotics is regarded as a technology with the potential to affect education by various researchers (Alimisis & Kynigos, 2009; Catlin & Blamires, 2010; Papert, 1980). An increasing number of articles, web pages, and various materials use the term Educational Robotics (ER) to refer to the use of robots in education. According to Anwar et al. (2019), 147 studies on K-12 educational robotics were published between 2000 and 2018. Despite this increase, there is no clear definition of what educational robotics is. According to Eguchi (2012), educational robotics is a unique learning tool that attracts and motivates students by creating a hands-on and at the same time fun learning environment. Stergiopoulou et al. (2016) defined educational robotics as a process in which students assemble and program their robotic systems to perform certain behaviors for educational purposes. Also, according to Angel-Fernandez and Vincze (2018), educational robotics is a field of study that aims to improve people's learning experience through the development and implementation of activities, technologies, and artifacts in which robots play an active role. From the definitions, educational robotics is a learning tool that is fun and attracts students' attention and has a high potential to be used in the teaching process. In addition to teaching certain concepts, it is used to attain skills such as robotics, problem-solving, reasoning, critical thinking, and effective cooperation (Alimisis, 2009).

For a robotic system to be functional, two types of activities must be performed namely development and programming. As a result of these activities, skills such as cognitive process skills and numerical thinking emerge, and these skills contribute to students' solving problems they encounter in real life as well as in the school environment (Karatrantou & Panagiotakopoulos, 2011). In addition, the development process and programming of the robotic system contribute to the socialization of the students with them cooperating for the implementation of the activities (Alimisis 2009). Considering this potential of robotics, it is of great importance to include robotics in learning environments.

ER activities are very diverse in terms of both robotic tools and methods of application to students. Certain ER activities are carried out in the form of extracurricular activities or club activities that are not integrated into the lessons. These extracurricular activities are generally accepted as students' first introduction to robotics, but they are not used to meet course objectives or assess performances (Baltes & Anderson, 2005). Despite these characteristics, extracurricular ER activities offer children the opportunity to think algorithmically and even learn mathematics informally. In extracurricular ER activities, participants can learn from their successes and failures without any academic pressure. Not having clear learning objectives, or not being in clear alignment with the curriculum objectives does not prevent students from learning and developing invaluable knowledge and skills that can later be transferred to a formal educational setting. For this reason, all kinds of extracurricular activities that offer children the opportunity to discover robots are valuable for their education (Komis et al. 2017).

## Theoretical Background

However, some researchers are of the opinion that ER alone cannot affect students' learning. Thus, they stated that an appropriate educational philosophy, learning environment, and teaching methodology are needed for the successful inclusion of ER in the education process (Alimisis, 2013). Although ER activities are integrated into formal education environments (usually with STEM activities) for this purpose, their level of compliance with the curriculum is variable. While designing ER activities in order to ensure subject teaching, the skills and learning objectives targeted by the curriculum should be met without departing from the main purpose of the course.

A suitable theory that could be integrated into learning environments, including the development, programming, and control of robots, was proposed by Papert (1980). This theory is the theory of constructionism, which is based on Piaget's constructivist approach. According to Ackermann (2001), while Piaget's constructivism theory explains how children's ways of doing and thinking develop over time and under what conditions children are more likely to abandon or retain the views they already hold, Papert's constructivism is more focused on the art of learning. or "learning to learn" and the importance of doing something in learning. Papert was interested in how students (themselves or others) come into contact with their work and how this communication enhances self-learning and ultimately facilitates the construction of new knowledge (Ackermann, 2001).

Various learning cycle models have been developed to use the constructivist approach in learning environments, regardless of whether they include ER activities. The constructivist learning approach aims to create rich learning experiences and to establish a student-centered democratic learning environment where students can interact with their peers (Bodner, 1986; Gürol, 2002; Sprague & Dede, 1999). Based on the relevant literature, the 5E learning model can be described as one of the most useful models of constructivist learning theory in the teaching process (Çoruhlu, 2013). The 5E model, developed by Bybee et al. (2006), is named after the English initials of the model (Engage, Explore, Explain, Elaborate, and Evaluate). In these stages, all the steps of a learning-teaching process that is based on research and inquiry are covered, and the roles of teacher and student are expressed in a rich way structurally and pedagogically throughout the process.

## Problem Solving Skills

One of the main goals of the Science Curriculum used in Turkey is to provide basic knowledge specific to the field. Also, among the general objectives of our education system is the development of students' problem-solving skills (Ministry of National Education [MoNE], 2018). Problem-solving can be defined in general terms as the process of eliminating the gap between the current situation and the desired situation, hindered by known or unknown factors (Huitt, 1992). The use and development of this concept in education were introduced by John Dewey. According to Dewey, the role of the teacher is to guide the students in solving the problem according to the interests and needs of the students and to help them attain problem-solving skills (Silik, 2016). Problem-solving skills are skills such as critical thinking, decision making, and creative and reflective thinking, which enable individuals to adapt to life and make them stronger in the face of life (Demirel, 2012).

## Literature Review

The adaptation studies of robotics, which started to be used as a learning tool with Papert (1980), are still continuing today. According to Talan (2020), there has been a steady increase in studies on educational robotics in the last ten years, and about three-quarters of these studies have been conducted in the field of information technologies and science. In addition, it was reported by Talan (2020) that the effects of ER on academic achievement as well as high-level thinking skills such as problem-solving, creativity, computational-thinking, and scientific-process skills were examined. The examination of the studies on the effect of robotics in subject teaching showed that robotics in subject teaching has a positive effect in general. For instance, Silva (2008), who developed robotic-assisted activities in the teaching of light and sound, revealed that students who used these activities improved their abilities in the physics course more than those who did not. Again in the field of physics, in another study on electricity, temperature, and magnetism, Badeleh (2019) obtained positive results. Song and Lee (2011) used STEM activities involving robots in math and science. At the end of 12 workshops, the academic achievement of the students in the experimental group, in which robots were used, was statistically significantly higher than the academic achievement of the students in the control group. In addition to the examples where positive results were obtained, there are also studies in which academic achievement did not increase, as in the studies of Lindh and Holgersson (2007). In the study conducted by Koray and Çakır (2020) at the 4th grade level with WeDo 2.0 robotic sets, although success and scientific process skills increased more in the experimental group, no statistically significant differences were observed.

Since the 5E learning model is a model that educators are familiar with, it has become a model used in the process of adapting robotic-assisted activities to the field of science education. Guven et al. (2022) used the 5E model in the implementation of Arduino-supported STEM activities and got positive results. Cakir and Guven (2019) developed an Arduino-supported robotics and coding activity based on the 5E learning model to teach the concept of pulse in the 6th grade science curriculum. In another study, Koray and Duman (2022) similarly developed an activity related to the concept of dynamometer in the 5th grade science lesson. Ghosh et al. (2019) reported that with the participation of 26 states in the United States, in-service trainings were given to teachers within the scope of the Next Generation Science Standards (NGSS) about STEM they were trying to develop. In these trainings, teachers adapted LEGO robotics activities to NGSS using the 5E learning model.

Considering the importance of problem-solving skills in human life, the question of whether robotic applications can be effective in the attainment of these skills has attracted the attention of educators. The examination of the studies exploring the effect of ER applications on problem-solving skills put forth that positive results are obtained in various age groups. Atmatzidou et al. (2008) observed that the problem-solving skills of middle and high school students who participated in a course aiming to increase their programming skills by using robots with a didactic approach improved. Another study conducted with 5th and 6th grade students determined that the problem-solving skills of the participants who learned to code using robots improved more than those who did not (Özer, 2019). In another study conducted with elementary school students, it was concluded that robotic applications improved students' problem-solving skills (Tatlısu, 2020). Furthermore, in his study with university students taking the Computer Programming course, Korkmaz (2016) reported that Lego Mindstorms Ev3 robot sets contributed to the development of problem-solving skills more than Scratch.

## Aim of the Study

Although there is no NGSS-like study in Turkey, according to the Science Curriculum (MoNE, 2018) updated in 2018, students are expected to make applications during the year as part of the Science, Engineering, and Entrepreneurship Applications at every grade level from 4th to 8th grade. Apart from the Ministry of National Education, the preparation of development roadmaps on topics such as artificial intelligence, sensor technologies, and robotics was emphasized as part of the infrastructure works for the implementation of the National Technological Advance addressed under the title of Critical Technologies of the Eleventh Development Plan (2019) of the Presidency of Strategy and Budget of the Republic of Turkey. It is apparent that the inclusion of robotics in the education process will contribute to achieving these goals. In light of the information in the literature, it is of great importance that ER be adapted to the curriculum in order to benefit from it at the desired level. While doing this, not placing an unnecessary workload on teachers and students will make it easier to achieve the desired result. For this reason, the 5E teaching model, a teaching model that teachers are familiar with, was preferred. Robotic activities were used at different stages of the model. The experimental application was planned for the learning objectives of the 5th grade science unit of "Propagation of Light". The purpose of the study was to reveal whether robotic-assisted applications had an effect on students' academic achievement and problem-solving skills. It is known that students have difficulties in solving open-ended questions (Öksüz & Demir 2019). Contrary to the common applications in the literature, multiple-choice and open-ended achievement tests were used together in the study, and the effect of the robotic-assisted activities used was desired to be measured in more detail. In the study, based on the subject-based curriculum approach, research-inquiry-based activities were designed in accordance with the learning outcomes. Since a robotic lesson design appropriate to the science learning objectives was used and it is an experimental study, it is believed that the study will contribute to the field literature. In addition to field-specific information, testing students' problem-solving skills is another aspect that adds value to the study. The originality of the study is that the activities were carried out with an easily programmable robot set, which has not been tested before and is suitable for children who do not have robotic experience.

Study Questions

1) Is there a significant difference between the experimental group, in which robotic applications were used, and the control group, in which the teaching was carried out in accordance with the curriculum, in terms of the multiple-choice academic achievement variable?
2) Is there a significant difference between the experimental group, in which robotic applications were used, and the control group, in which the teaching was carried out in accordance with the curriculum, in terms of the open-ended academic achievement variable?
3) Is there a significant difference between the experimental group, in which robotic applications are made, and the control group, in which the instruction is carried out in accordance with the curriculum, in terms of the problem-solving skills variable?

## Method

The experimental research method, one of the quantitative research methods, was employed. The pretest-posttest control group design, a quasi-experimental research method, was utilized. Experimental studies aim to test the effect of the independent variables on the dependent variable. The main purpose of these studies is to reveal the cause-and-effect relationship between the variables. For this purpose, after random assignment to the treatment groups, the independent variable is manipulated and the variables that may affect the dependent variable are controlled (Büyüköztürk et al., 2018; Fraenkel et al., 2012). In the study, the independent variable whose effect on the dependent variables of "academic achievement" and "problem-solving skills" was examined is the "robotic applications".

Table 1. Standard notation of the study design

| Group | Measurement I | Process | Measurement II |
|---|---|---|---|
| **E** | AAT1 | X1 | AAT2 |
| | PSST1 | | PSST2 |
| **C** | AAT1 | X2 | AAT2 |
| | PSST1 | | PSST2 |

E: The experimental group in which robotic applications were used.
C: The control group in which activities based on the science curriculum were used.
X1: Robotic-assisted activity applications.
X2: Applications offered by the curriculum.
AAT: Multiple-choice and open-ended Academic Achievement Test for the unit of Propagation of Light.
PSST: Problem-Solving Skills Test.

### Study Group

The study was carried out with 5th grade students who were attending a public school in Turkey located in a district center in the Western Black Sea region in the 2019-2020 academic year. Two classrooms were included in the study. Taking into account the classroom sizes and students' grade point averages, one of these classrooms was assigned as the experimental group and the other as the control group. While the experimental group was made up of a total of 17 students, eight females, and nine males, the control group was made up of a total of 19 students, nine females, and 10 males. The robotics-based activities were used with the experimental group students, whereas activities offered by the curriculum were used in the control group. The application times of both groups were equal and it was accepted that the groups were not affected by each other.

**Research Process**

Before the procedure, the Academic Achievement Test (AAT) and the Problem-Solving Skills Test (PSST) were administered to the students in the experimental and control groups as a pretest. After the experimental and control groups were randomly determined, the students in the experimental group were given basic robotics training for two weeks on the use of the O-Bot education set as part of the "Program Solving and Programming" unit of the "Information Technologies and Software" course. As part of the basic robotics training, the parts of the robot set were introduced in the first week, and information on how to use it was provided. In the second week, how to program the designed robots was explained through sample applications. During these two weeks, the activities offered by the curriculum were used with the control group students in the "Information Technologies and Software" course.

In the present study, the unit "Propagation of Light" was selected. The reason for selecting this unit was that the unit's learning objectives were believed to be compatible with the robotic activities to be done. Before starting the applications for the learning objectives, teacher instructions and student worksheets were developed for both groups. Each activity for the experimental group, in which teacher instructions and student worksheets developed based on the 5E learning model were used, was related to the learning objectives of the "Propagation of Light" unit of the 5th grade science course and required the use of O-Bot robotic sets. Robotic activities were included in the phases of explore, explain and elaborate. The same activities for the control group were adapted based also on the 5E learning model, without requiring the use of robots.

The applications designed for the unit learning objectives continued for four weeks (a total of 16 periods, four periods a week, as stipulated by the curriculum. The application was carried out by the researcher, and the course teacher participated as an observer. While the experimental group students achieved the unit learning objectives with robotic-assisted applications, the lessons were taught in the control groups by using the student-centered activities and teaching methods and techniques offered by the curriculum. In the week following the completion of the activities, the AAT and the PSST were administered to both the experimental and control group students as a posttest. The study continued for a total of six weeks, with the administration of the pretest and posttests (excluding the basic robotics training).

**Data Collection Tools**

In the research, the Multiple-Choice AAT, the Open-Ended AAT, and the PSST were used.

*Academic Achievement Tests*

Developed as open-ended and multiple-choice, the academic achievement tests cover the subjects in the "Propagation of Light" unit in the 5th grade science curriculum. In both tests, attention was paid to the equal distribution of questions related to each learning objective of the subjects, and the content validity of the tests was ensured by consulting the opinions of four field experts. The first multiple-choice academic achievement test, consisting of 32 questions, was reduced to 29 questions in line with the expert opinions, and 27 after the reliability study. Reliability studies were conducted with the Iteman software program after administering the multiple-choice achievement test to a total of 51 students, and the KR-20 value was determined as 0.739. The first open-ended academic achievement test, consisting of 17 questions, was reduced to 16 questions in line with the expert opinions. The reliability study of the open-ended achievement test was conducted with two field expert raters. The correlation coefficient between the means of the scores given to the items by the raters was found to be 0.87. In achievement tests, each question is scored equally, and the highest possible score is 100. The tests were administered to the experimental and control groups for 40 minutes as a pretest and posttest.

*Problem-Solving Skills Test*

Students' problem-solving skills were measured using the Daily Life-Based Problem-Solving Skills Test (DLPSST) developed by Pekbay (2017). Developed to assess the "Decision-Making", "System Analysis and Design" and "Problem-Solving" processes, the test is made up of 18 questions. Having 10 difficult, seven medium, and one easy open-ended question, the test difficulty mean was found to be 0.34. The highest score that can be gotten from the test, which is rated as 0-1-2-3, is 54 and the lowest score is 0. The Cronbach's alfa reliability coefficient of the test was 0.86.

**Data Analysis**

A statistical software program SPSS 20 was used in the analysis of the data. Appropriate statistical methods were tried to be determined by investigating the suitability of the data to the normal distribution and the homogeneity of the variances. Since the number of participants in each group was less than 50, Shapiro-Wilk test was used for the assumption of normality (Mishra et al., 2019). Levene test was used to determine the homogeneity of the variances of the data. As a result of the analysis, it was decided to use parametric tests because the data set had a normal distribution ($p>.05$) and the group variances were homogeneous. In this context, in order to test whether there was a significant difference between the variables, the collected data were analyzed using the t-test for independent groups. For interpretation, the significance level for the hypothesis tests was set to .05.

**Threats to the Internal Validity of the Study**

Interpretation of the results in this study depends on the effects of threats on the internal validity of the study. First, selection bias was examined by taking into account the grade averages and pretest results of the previous semester's science course. No difference between the groups was found in terms of these variables. Also, none of the participants participated in an activity related to robotics. The maturation effect was very limited and the groups showed differences in the posttests regarding the dependent variables. If there is a maturation effect, both groups will be the same or similar to each other in the posttests after the application. In addition, since there was no significant event related to the dependent variables of the study and the application process before the application, any past effects did not affect the study.

Measuring tool effect, as a different threat, was checked in both applications using the same items, the order of application of the tools, and the same data collector. Another issue related to the measurement tool administration is that six weeks is accepted sufficient to prevent the pretest effect. Due to official restrictions, the tools were not administered to another group only as a posttest to check for test effect. Furthermore, experimenter bias was prevented by an independent observer observing the applications in both groups.

**iDea Visual Programming Flowchart and O-Bot Robot Kit**

Coding refers to all commands or a part of a series of commands written on the computer, electronic circuits, or mechanical systems in order to perform an operation or achieve a specific purpose (Guven et al., 2022). Programming language, on the other hand, is a set of commands consisting of special words and symbols used so that the electronic devices and hardware used can serve the determined purposes (Arslan & Tanel, 2017). The task of writing a program, which seems to be complex, becomes much easier thanks to visual programming. Integrated Development environment for applications (iDea) is a visual programming software that has a Turkish user interface providing the development tools we need to turn an idea into an application, and enabling the preparation of algorithms in Turkish (Robotsan, 2021).

Developed by Turkish engineers, O-bot is a wheeled robot kit consisting of iDea control card and robot components that can be mounted on two carrier platforms, and are easy to install. Created based on the do-it-yourself philosophy, it is reprogrammable. Various sensors (such as light, temperature, distance, sound, and motion) and producers (such as sound, and light) that can work in harmony with the control card are offered with the robot set. The O-bot can be programmed with iDea visual programming software, whose language is Turkish.

The products of the Lego company and Arduino-based products are widely used in robotic activities. There are several reasons why O-bot is preferred in this study. First, this platform is relatively new compared to the others and has not been used before in activities aimed at the learning objectives of the science course. Second, this platform can be programmed in two different ways. The first is by using flowcharts that are appropriate for children mainly attending elementary and middle schools with no programming experience. The second is by using rsBasic programming commands based on the BASIC programming language, appropriate for those with more advanced programming knowledge (Figure 1). The third reason why we preferred this platform was that its cost was lower than the others.

The biggest drawback of this robot kit is its exterior. As mentioned above, when the robot components are mounted on carrier platforms, as in Lego Mindstorms, it does not give the robot a human-like appearance

(Figure 2). However, this disadvantage can be turned into an advantage by using the creativity of teachers and students. Robots can be transformed into the desired shape with the help of various game blocks and different stationery materials that can be mounted on the carrier platforms.

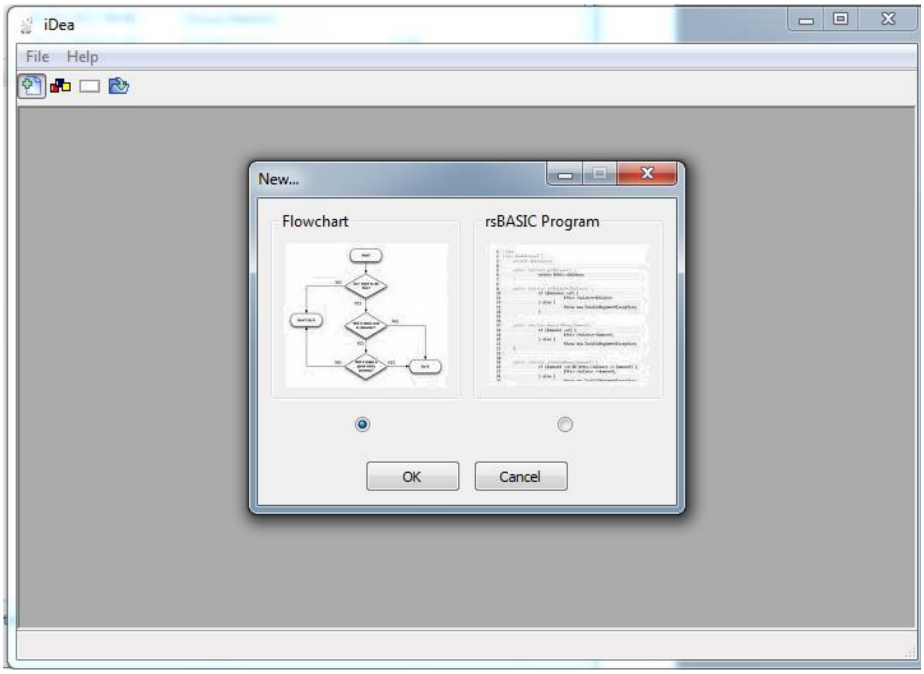


Figure 1. Flowcharts and rsBASIC options in the iDea program development environment

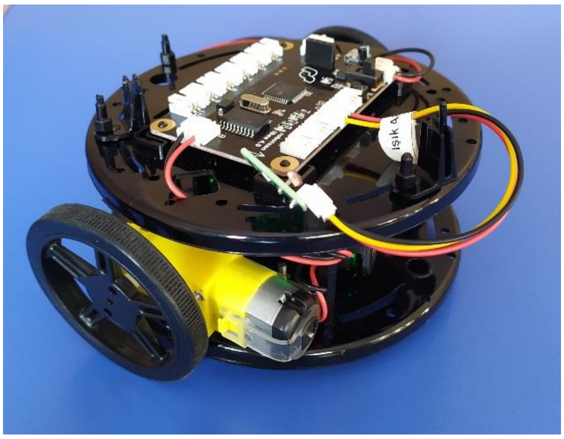

Figure 2. Installed O-bot kit.

**Preliminary Analysis of the Experimental and Control Groups**

In the study, the experimental and control groups, which were determined as the study group, were compared in terms of various variables. As seen in Table 2, the total number of students in the experimental group was 17 (eight females and nine males), and the number of students in the control group was 19 (nine females, and 10 males). Both groups had 47% females and 53% males. According to the data results, the distribution of students in the groups was equal in terms of number and sex.

Table 2. Descriptive information on the number of students in the experimental and control groups

| Groups | Total | | Female | | Male | |
|---|---|---|---|---|---|---|
| | N | % | N | % | N | % |
| Experimental | 17 | 47 | 8 | 47 | 9 | 53 |
| Control | 19 | 53 | 9 | 47 | 10 | 53 |

Independent samples t-test analysis was conducted to compare whether the students were equivalent in terms of their previous semester's science grade averages, multiple-choice AAT test scores, open-ended AAT scores, and

PSST scores. The results of the independent samples t-test analysis of the 5th grade first semester science grade averages of the experimental group and control group are presented in Table 3.

Table 3. 5th grade first semester science grade averages of the experimental group and control group

| Group | N | $\bar{X}$ | SD | df | t | *p* |
|---|---|---|---|---|---|---|
| Experimental | 17 | 91.39 | 9.8 | 34 | -1.70 | .09 |
| Control | 19 | 84.54 | 13.68 | | | |

p<.05

As seen in Table 3, there was no significant difference between the 5th grade first semester science grade averages of the experimental and control group students. (t(34)=-1.7, p>.05). Accordingly, it can be said that the groups were equivalent in terms of their 5th grade first semester science grade averages before the application. Whether there was a significant difference between the multiple-choice AAT pretest scores of the experimental and control groups was compared using the independent samples t-test analysis and the results are presented in Table 4.

Table 4. Independent samples t-test analysis results of the multiple-choice aat pretest scores of the experimental and control group students

| Group | N | $\bar{X}$ | SD | df | t | *p* |
|---|---|---|---|---|---|---|
| Experimental | 17 | 44.16 | 17.68 | 34 | -.26 | .80 |
| Control | 19 | 42.88 | 11.29 | | | |

As seen in Table 4, there was no significant difference between the multiple-choice AAT pretest scores of the experimental group and the control group. (t(34)=-.256, p>.05). According to these results, it can be said that the groups were equivalent in terms of their multiple-choice AAT pretest scores before the application. Whether there was a significant difference between the open-ended AAT pretest scores of the experimental and control groups was compared using the independent samples t-test analysis and the results are presented in Table 5.

Table 5. Independent samples t-test analysis results of the open-ended aat pretest scores of the experimental and control group students

| Group | N | $\bar{X}$ | SD | df | t | *p* |
|---|---|---|---|---|---|---|
| Experimental | 17 | 19.81 | 7.18 | 34 | -1.60 | .12 |
| Control | 19 | 14.93 | 10.95 | | | |

As seen in Table 5, there was no significant difference between the open-ended AAT pretest scores of the experimental and control groups (t(34)=-1.6, p>.05). According to these results, it can be said that the groups were equivalent in terms of their open-ended AAT pretest scores before the application. Whether there was a significant difference between the PSST pretest scores of the experimental and control groups was compared using the independent samples t-test analysis and the results are presented in Table 6.

Table 6. Independent samples t-test analysis results of the psst pretest scores of the experimental and control group students

| Group | N | $\bar{X}$ | SD | df | t | *p* |
|---|---|---|---|---|---|---|
| Experimental | 17 | 29.06 | 6.28 | 34 | -.80 | .43 |
| Control | 19 | 26.37 | 13.04 | | | |

As seen in Table 6, there was no significant difference between the PSST pretest scores of the experimental and control groups (t(34)=.80, p>.05). According to these results, it can be said that the groups were equivalent in terms of their open-ended AAT pretest scores before the application.

## Findings

In this section, the findings of the study sub-problems obtained as a result of the application are presented, and the data are explained in tables. Findings, interpretations, and tables are organized in order of the study sub-problems. The results of the independent samples t-test analysis regarding the first study question are given in Table 7.

Table 7. Independent samples t-test analysis results of the multiple-choice aat scores of the experimental and control group students

| Group | N | $\bar{X}$ | SD | df | t | *p* |
|---|---|---|---|---|---|---|
| Experimental | 17 | 53.03 | 19.10 | 34 | -2.15 | .04 |
| Control | 19 | 39.25 | 19.22 | | | |

According to Table 7, the multiple-choice AAT mean scores of the experimental group in which robotic applications were used were higher (53.03) than the multiple-choice AAT mean scores of the control group in which activities based on the science curriculum were used (39.25). This difference was statistically significant (t(34)=-2.15, p<.05). The Cohen d effect size was calculated as medium (0,72). The results of the independent samples t-test analysis regarding the second study question are given in Table 8.

Table 8. Independent samples t-test analysis results of the open-ended aat scores of the experimental and control group students

| Group | N | $\bar{X}$ | SD | df | t | *p* |
|---|---|---|---|---|---|---|
| Experimental | 17 | 37.17 | 14 | 34 | -3.61 | .00 |
| Control | 19 | 20.58 | 13.54 | | | |

According to Table 8, the open-ended AAT mean scores of the experimental group in which robotic applications were used were higher (37.17) than the open-ended AAT mean scores of the control group in which activities based on the science curriculum (20.58). This difference was statistically significant (t(34)=3.61, p<.05). The Cohen d effect size was calculated as high (1.73). The t-test analysis results for the independent groups regarding the third study question are given in Table 9.

Table 9. Independent samples t-test analysis results of the psst scores of the experimental and control group students

| Group | N | $\bar{X}$ | SD | df | t | *p* |
|---|---|---|---|---|---|---|
| Experimental | 17 | 36.29 | 7.82 | 29.13 | -3.72 | .00 |
| Cntrol | 19 | 22.63 | 13.72 | | | |

According to Table 9, the PSST mean scores of the experimental group in which robotic applications were used were higher (36.29) than the PSST mean scores of the control group in which activities based on the science curriculum were used (22.63). This difference was statistically significant (t(34)=3.61, p<.05). The Cohen d effect size was calculated as high (1.22).

## Discussion

According to the general result of the present study, robotic applications used in science had positive effects on academic achievement and problem-solving skills. Based on the study findings, the results for the study questions are as follows:

1. There was a significant difference between the multiple-choice AAT scores of the experimental group in which robotic applications were used and the control group students who are taught in line with the science curriculum in favor of the experimental group.
2. There was a significant difference between the open-ended AAT scores of the experimental group in which robotic applications were used and the control group students who are taught in line with the science curriculum in favor of the experimental group.

Although the factors affecting students' academic achievement in Turkey are very varied, according to a meta-analysis study conducted by Sarıer (2016), these factors can be grouped under three categories, namely school, student, and family. In terms of effect size, it is possible to rank these groups as student, family, and school from largest to smallest. It was determined that self-efficacy and motivation factors had the greatest effect among student-based factors. Among the school-based factors, the biggest effect was determined as the attitude towards the course. According to Cohen et al. (2007), values in the range of 0.30-0.50 are interpreted as medium. The studies in which robot sets were used in classroom activities revealed that such activities increase the attitude and motivation towards the science course (Mitnik et al., 2008; Nugent et al., 2009; Uşengül, 2019). Considering these known effects of robotics, although such a determination was not made in the present study, the increase in achievement can be associated with a possible increase in attitude and motivation towards the course.

The literature results of the studies on robotic applications put forth that robotic applications increase academic achievement (Kert et al., 2020; Yang et al., 2023). For instance, the study conducted by Özdoğru (2013) with 6th grade students in the science and technology course determined that the academic achievement of the group being taught with Lego Mindstorms NXT 2.0 robot kits increased. Similar results were found by Şimşek (2019). As a result of the work carried out by Şimşek (2019) with O-bot robot sets within the scope of the 6th grade "Matter and Heat" unit, the experimental group in which the robotic coding activities were done was more successful than the control group. Uşengül (2019) also carried out a similar study with Lego WeDo 2.0 robot sets in the 5th grade science course and determined results in favor of the experimental group.

In studies on academic achievement, multiple-choice and open-ended tests were generally administered together and not assessed separately. In our study, as mentioned in the Findings section, these tests were assessed separately. According to Tables 4, 5, 7, and 8, multiple-choice test means in both pretests and posttests were higher than open-ended test means. The literature also showed that students are generally more successful in multiple-choice questions than in open-ended questions (Öksüz & Demir 2019). In the present study, the examination of the difference between the pretest and posttest means of the experimental group for both achievement tests revealed a 17,36 points increase in the open-ended achievement test, whereas this increase was 8,87 points in the multiple-choice test. Although multiple-choice tests have many advantages, it is known that they are not as successful as open-ended tests in measuring high-level cognitive skills (Bahar et al., 2012; Üstüner & Şengül, 2004). Considering the magnitude of the increase in the open-ended test scores, it can be concluded that the high-level cognitive skills of the students were also positively affected as a result of the application.

Another conclusion that can be drawn from the study is that the 5E teaching model is very effective for teachers to implement robotic activities in the classroom environment. The 5E model allows the use of robotic activities at different stages of the course. Guven et al. (2022) developed Arduino-supported robotic activities related to energy, sound, electricity and circulatory systems and applied them to students using the 5E model. As a result of the research, it was determined that the creativity, attitude and motivation levels of the students increased with the robotic coding activities integrated into the 5E learning model applied in science subjects. In addition, it was determined that the students produced many creative ideas about using robotic coding applications in solving various problems encountered in daily life and they were very willing to use such applications in science lessons.

It was determined that there was a significant difference between the PSST scores of the experimental group in which robotic applications were used and PSST scores of the control group students who were taught in accordance with the science curriculum in favor of the experimental group. Considering that DLPSST, which was used as a measurement tool in the study, measures "decision-making", "system analysis and design" and "problem-solving" behaviors (Pekbay, 2017), it can be said that these behaviors also developed after the application. In the literature, studies examining the effect of robotic applications on problem-solving skills come second after studies examining the learning level/achievement variable. Positive results were obtained in most of these studies (Talan, 2020). For instance, Özer (2019) found that coding studies using robots improved problem-solving skills more than those that did not. Similarly, Çalışkan (2020) also revealed that robotic programming had a positive effect on students' problem-solving skills. Although positive results were generally obtained in the studies exploring the effect of robotic activities on problem-solving skills, there are also researchers who could not observe a positive effect, such as Hussain et al. (2006).

## Recommendations

As seen in the study results, the use of robotic-assisted activities in science lessons has positive effects. In order for robotic-assisted activities to be more effective, it is recommended that students be given coding education in the information technology courses, and then robotics applications in the science courses should be started. Considering that robotic programming develops daily problem-solving skills, it is recommended that students are given lessons where the lessons are associated with daily life. However, the generalizability of the study results is limited due to the small number of participants. In the future, a quasi-experimental study with more participants should be planned. In addition, the present study can guide researchers in examining the effects of robotic coding applications integrated into the 5E learning model in science teaching on different variables. Furthermore, it is recommended that teachers receive in-service training for such applications and that schools establish laboratories with sufficient technical equipment for robotic coding applications. In our research, since the students were introduced to robot sets for the first time, the programs they would use were given ready. For students who have longer experience with robotic applications, applications where they can write their own codes should be planned and their effects on various variables should be investigated by researchers. It is recommended to include these studies within the scope of engineering design applications (MoNE, 2018), which is also emphasized in the science curriculum, or STEM applications in general.

## Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in JESEH journal belongs to the authors.

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