Pegem Journal of Education and Instruction, Vol. 15, No. 3 , 2025 (pp. 145-161)

CASE STUDY **WWW.PEGEGOG.NET**

Do Educational Robotics Technologies Integrated with 3D Fesign Improve the Project and Engineering Design Process Skills of Gifted Students: Case Study

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Abstract

Three-dimensional (3D) technologies and robotic tools are new educational instruments that have entered our lives with the rapid development of technology. This study aims to investigate the effects of integrated teaching with 3D technologies and robotic tools on the development of engineering and project design skills of gifted students. A case study was used in the study. The study participants were eight secondary school students attending a science and arts center in a public school system. Data were collected using student interview forms, a rubric for engineering and project design skills, an observer-teacher rubric, student and researcher diaries, and document analysis. The results showed that students generally developed their skills in applying engineering design skills, presented project designs on various topics, and used 3D technologies and robotics tools by integrating them into solving problems in daily life. The results also showed that students improved their ability to pose everyday problems and connect them to the science course, create research questions, and establish cause-and-effect relationships to the problem.

Keywords: 3D technologies, educational robotic tools, engineering design, Project design skills

Introduction

The worldwide curriculum aims to cultivate people for countries with twenty-first-century skills who are creative and can look at events and phenomena from different perspectives to solve problems in daily life. With Industry 4.0 named the new industrial revolution, smart factories are being set up with new-generation technologies such as 3D technologies and robotic tools, and high-value-added technologies are being offered for the benefit of humanity. All these changes bring new opportunities and enable the use of new technologies. In particular, gifted students are essential for countries that find new opportunities through new technologies. Because gifted students have different characteristics than their peers regarding their development, learning behaviors, and cognitive levels, educational programs need to be differentiated for these students (General Directorate of Special Education and Guidance Services [ORGM], 2021).

In recent years, workshop classes involving robot programming and 3D technologies have been established in schools. The goal of these classes is for students to use robotics tools and 3D technologies to find solutions to the problems they face in their daily lives. Students must also apply the project-based learning approach when designing a project using 3D technologies and robotics tools. Following Dewey's ideas, Kilpatrick (Pecore, 2015) stated that projects should help children engage in activities appropriate to their age and develop a deep understanding of their world (Williams, 1998). Kilpatrick divided projects into four types. Type 1 is ideas that can be thought about and planned (e.g., boat building). Type 2 ideas that involve an esthetic experience (listening to a poem, liking a painting). Type 3 was expressed as problem-solving (interpreting the results of an experiment), and Type 4 as ideas (writing for a class) that involve acquiring a particular skill or knowledge. (Knoll, 2010). In this study, problem-solving project ideas, which Kilpatrick referred to as Type 3,

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How to cite this article: Akyol C , Karakuş F. Do Educational Robotics Technologies Integrated with 3D Fesign Improve the Project and Engineering Design Process Skills of Gifted Students: Case Study. Pegem Journal of Education and Instruction, Vol. 15, No. 3, 2025, 145-161

Source of support: Nil

Conflicts of Interest: None.

DOI: 10.47750/pegegog.15.03.15

Received: 13.08.2024

Accepted: 21.01.2025 **Published:** 01.07.2025

were used. With this project, we aimed for students to solve the problems of their daily school life (Aktan, 2016).

Project-based learning is also associated with the constructivist approach (Karakuş, 2019). Project-based learning consists of defining the problem, finding solutions, obtaining research data, and analyzing data that can be defined as a problem and finding solutions to that problem. In science and art centers where gifted and talented students are taught, students are expected to produce projects and make applications for patents to protect their intellectual rights. To this end, scholars believe that students can acquire twenty-first-century skills by integrating 3D technologies and robotic tools (robotic cards, digital and analog sensors/sensors, and control cards)

Engineering Design Process

The engineering design process (EDP) involves the development of practical problem-solving skills in the learning process (Li et al., 2016). Gifted students are expected to use their highly developed thinking skills to develop solutions to problems and collaborate on interdisciplinary projects. EDP involves identifying the problem, searching for possible solutions, defining the solution, and disclosing and testing a prototype (Bozkurt, 2014). EDP is a cyclical process that begins with identifying a problem and ends with a solution (Committee on Standards for K-12 Engineering, 2010). According to Hynes et al. (2011), the cyclical process of EDP looks like Figure 1. Hynes et al. (2011) describe EDP as an interactive process that practically promotes learning and creative thinking (Hynes et al., 2011, p. 8). Creative and exceptional thinkers are necessary to produce value-added technological products. For example, 3D technologies and robotic tools are essential technological products. These technologies are now widely used in medicine, defense, the food industry, and space exploration. Considering that the variety of products supported by 3D software technologies is increasing daily, the innovative and easy accessibility of these technologies makes people's lives easier. For example, drawing a broken part at home with a 3D design program and fixing it with a printout from a 3D printer is an excellent relief for daily life.

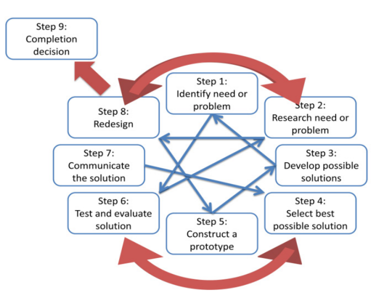

Fig. 1: Engineering Design Process Steps (Hynes, et al., 2011)

3D Technologies and Science Education

Researchers have recently begun using 3D technologies in science education (Halaç & Bozdoğan, 2019). Researchers have reported that students can develop their imagination by transforming their ideas into tangible products using 3D technologies (Lin at al., 2021). According to Brown (2015), 3D technologies in STEM have helped to increase students' motivation to produce new ideas. 3D technologies allow students to touch the objects they design, which is a unique experience. In a more recent study, Akyol et al. (2022) found that 3D technologies motivate students as they create projects.

An analysis of the literature shows that research studies on 3D technologies and science education mainly have focused on students' attitudes (Gürel Taşkıran, 2019), achievement (Çekirge, 2019), and the teaching of some topics (Avinal, 2019). For example, Çetin et al. (2019) investigated secondary students' experiences in the 3D design process. Their results revealed that students' design skills improved after training in 3D technologies. In another study, Şen et al. (2020) found that seventh-grade students used 3D technologies to develop skills such as planning, designing, creating a prototype, testing, and evaluating product performance. In the other study, Chien (2017) found that high school students who used 3D printing technologies could be made more accurate predictions during the activities.

These results from the literature show that 3D technologies are mainly used as a tool for material development in science and engineering education (Yıldırım et al., 2018). In this study, students are expected to develop functional and applicable solutions to everyday problems by integrating 3D technologies with various technologies. Therefore, we hypothesized that combining these technologies with robotic technologies can positively influence students' design skills and project development processes. However, we note that 3D technologies can also be used in the classroom to support the production of learning objects and may positively influence students' knowledge and skills related to design processes. Creating a design with 3D technologies contributes to developing students' creativity and problem-solving skills (Kökhan & Özcan, 2018).

Robotic Tools and Science Education

Robots are also popular technological tools that have great potential to improve student science literacy in science classrooms (Sullivan, 2008). Robotic components can be easily used in science classrooms, either through the internal sensors they contain or through the sensors that can be integrated. For example, the Lego Mindstorm EV3 kit, which includes ultrasonic, color, distance, and gyro sensors, can be easily used in science experiments and offers essential benefits in developing projects to solve everyday problems.

In the existing literature, we find that Lego Mindstorm EV3 and Lego NXT kits are used in studies on robotic vehicles (Şen et al., 2021; Tatlısu, 2020; Li et al., 2016; Kuş, 2016; Koç Şenol & Büyük, 2015). We found that the sensors included in the Lego kits (color, gyro, ultrasonic, and distance sensors) are the most commonly used. On the other hand, the Vernier LabView sensors (pH, temperature, gas pressure, conductivity, force, electrical voltage) that harmonize with the Lego Mindstorm EV3 kits are not generally used. We found that the studies using these sensors are mostly activity-based (Ramos et al., 2020; Ishafit et al., 2020; Hui, 2016). The research studies conducted with middle school students have primarily focused on the effects of instructional materials (Halaç & Bozdoğan, 2019; Kuş, 2016), attitudes toward science (Akman Selçuk, 2019; Kim & Lee, 2016; Gürel Taşkıran, 2019; Özüorçun, 2019), achievement (Akçay, 2018; Erdoğan & Çınar, 2021; Song & Lee, 2011; Kılınç, 2014), and twenty-first century and problem-solving skills (Erdoğan, 2019; Karaahmetoğlu, 2019). For example, Welch and Huffman (2011) found that extracurricular robotics competitions increased students' interest in science subjects. In a recent study, Eroğlu (2021) found that building educational robots significantly increased seventh-grade students' achievement and creativity in the subjects of force and energy. In another study, Akman Selçuk (2019) found that educational robotics applications conducted with sixth-grade students positively influenced students' attitudes and skills. The results of the research studies show that the studies primarily focused on printing course materials and pre-made designs to attract students' attention and engage them in robotics competitions. However, we found that no study has yet been conducted on the use of robotic tools in solving everyday problems and designing projects.

Research Problem

The studies on robotic tools mainly investigated students' achievement, thinking skills, and attitudes. However, no studies considered integrating 3D and robotic tools into science education. In addition, we found no study on students' engineering skill development and project design process in the literature. Given this information, we could not find any studies on the effects of 3D technologies, robotic tools, and sensors on gifted students' engineering skill development and project design process. Although the use of 3D technologies and robotic tools in science education has become popular in recent years, a study investigating the development of engineering and project design skills of students using 3D and robotic tools has demonstrated the need for the present research. Considering that research on 3D technologies and robotic devices in science education is minimal, the contribution of these technologies to the engineering and project designing processes in science education is becoming increasingly important and valuable for scholars in science education. Moreover, the literature still needs to address how to integrate robotic tools and 3D technologies into science education (Sinap, 2017). Because of these reasons, this study aims to investigate the effects of 3D technologies and robotic tools on developing gifted students' engineering and project design skills.

Significance of Research

Researchers have indicated that 3D technologies and robotic tools help students navigate and solve everyday problems (Akyol et al., 2022). The results of this research, which aims to integrate 3D technologies and robotic tools into science teaching and to investigate the development of students' skills in EDP and the project design process, will be an actual application example for teachers who will use these technologies in science classrooms. Moreover, the results obtained from this study will positively contribute to solving students' everyday problems and realizing their project ideas. In addition, the results of this study will provide valuable insights to textbook authors and curriculum designers on how to use these technologies in science and technology education. Thus, this study investigates the effects of 3D technologies and robotic tools on developing gifted students' engineering and project design skills.

The sub-problems of the study are as follows:

- What is the current situation regarding 3D technologies and robotic tools in pre-teaching science classrooms?
- What is the skill development of students using 3D technologies and robotic tools in science education after teaching, in terms of design and project design process?

Method

Research Design

This study used a case study approach, one of the designs of qualitative research methods, and incorporated the nested single case model. The case study is a qualitative research approach in which the researcher examines one or more limited situations over time, using various data tools such as observations, interviews, documents, and reports to define the situation or situations (Creswell, 2007). A case study can be used when the researcher focuses on how and why events and phenomena occur and wants to examine the event or phenomenon under its natural conditions (Yin, 1984). In this study, we preferred a case study to identify the situation related to students' engineering and project design skills and to evaluate the development of project development and engineering planning process skills.

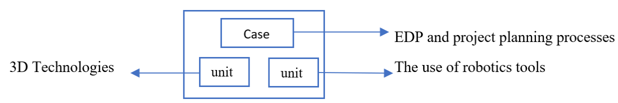

Fig. 2: A Single Case Study Model (Yin, 2003: 40, cited by Aytaçlı, 2012)

Participants

Researchers conducted this study in a science and art center in the Central Anatolia region of the Republic of Turkey during the academic year 2021-2022. In the study, we used non-random sampling and purposive selection to conduct an in-depth study to answer the study's research questions. We used a criteria-based sampling method in selecting participants who agreed to participate in this study (McMillan & Schumacher, 2006). Our sampling criteria required participation from students who had taken at least one semester of a 3D design and robotics course at a middle school. All participants volunteered for this study. They were gifted students. We used pseudonyms for each student to comply with ethical rules. The students were coded as Mert^{B1D}, Aylin^{B1K}, Nur^{B2D}, Aybüke^{B2D}, Remzi^{B2Ö}, Önder^{B2Ö}, Eren^{B2D}, and Okan^{B2D}. In the codes, the "B" in the upper character represents the continued semester and year, and the letters "D" and "Ö" indicate if the student is from a private or public school. The demographic characteristics of the participants are shown in Table 1.

Research Process

For the implementation in the research, we used the 7E method in the courses. We created lesson plans using the 7E teaching method based on the constructivist approach. Before we began the six-week implementation of the research, we held preliminary meetings with the students. During these meetings, we asked students to complete the data collection forms. We did not count this time toward the implementation period. Before we began implementation, we also gave the students a brief introduction to the Lego Mindstorm EV3 kit and the Tinkercad program. This process took two weeks and four class periods. During this process, we asked students to develop project ideas and enter them into the project idea notebook and the engineering solution process form. After completing the preliminary meetings with the students, we began to implement the main activities of the study.

In the first week, the students had the task of designing a gear in the program TinkerCad and then integrating these designs into the large Lego engine so that they learned the basic principles of gears of simple machines. They had the opportunity to observe the impellers, test variables such as the number of gears and the ratio of radii, the direction of rotation, and the number of rotations, and see how they identified and worked out solutions to everyday problems associated with them. The touch, color, and distance sensors of the Lego Mindstorm EV3 kit were introduced, and students did remind about looping. In the second week, a station activity was conducted where students learned about the pH, temperature, and gas pressure sensors. The Vernier force sensor was used in the third week, and activities on inclined planes and levers were conducted. The students designed their inclined plane and moved the cart with the inclined plane on this plate. They also tested the angle of the inclined plane and the value measured by the force sensor, the mass of the trolley of the inclined plane, and the force magnitudes applied to the stationary force sensor. Daily life problems were studied for which they could find solutions using the information obtained from the activity. The students were asked to fill out the data collection tools. In the fourth week, the students presented their projects to the observing teacher and their classroom mates. This week's activities related to humidity, light, and UV light sensors. In another

Table 1. Students' Demographic Information

Students	*Ongoing Period Gender Continue Program Time*	*Gender*	*Time spent by the student in the program*	*School Type*
MertB1D AylinB1D	BYF1	Male Female	0-1 Year	Public Middle School
NurB2D, AybükeB2D ErenB2D, OkanBB2D	BYF2	Female Male	1-2 Year	Public Middle School
RemziB2Ö, ÖnderB2Ö	BYF2	Male	1-2 Year	Private Middle School

week, we asked students to design their experiments using all sensors. Students were also asked to present their experiment designs in Google Classroom before the lesson. During the activities, students received feedback on EDP regarding the data collection tools and information about the integration processes.

The integration of 3D technologies was ensured in all activities. For example, they were asked to create a design that would allow the pH sensor to stand upright when measuring the pH of various liquids. After each sensor presentation and 3D integration, students sought to develop solutions to one or more everyday problems using the information they learned. During this process, they were asked to complete the EDP form. In the final week, students had the opportunity to present their ideas and designs on these ideas.

Apart from the presentations in the last week, in the third week of the implementation process, two technology design science teachers, who were invited to the class and selected one of the project ideas identified by the students, gave ten-minute project presentations to students. The observing teachers completed a rubric for observations that included EDP and skills in the project development process. All three observers were teachers who worked at the Science and Art Center and had experiences with projects. In the third week, the students revised the projects they had selected, taking into account the feedback and suggestions they had received and made a presentation to the same panel of judges and their friends from the previous week. Students prepared their presentations from the last week and shared them in Google Classroom. During the week following the teaching, students were asked to test their designs. The implementation process was conducted both in person and through the virtual classroom. Researchers held two hours of weekly instruction with the students for six weeks. The reason for the two hours of instruction per week is that the course hours set for students were limited to two hours per week.

Table 2: Research process

Weeks	**Before teaching**
1. Week	Obtain parental permission
	Conduct preliminary interviews
	Invite students to contribute project ideas
2. Week	Provide information about the process
	Collecting project ideas and processing them on forms
	Reading interview transcripts aloud to participating students
	Teaching process
1. Week	Gears and motors
2. Week	Discovering Vernier sensors/ project presentations
3. Week	Force/ inclined plane levers/ review of gear outputs/ interview
4. Week	Discovering Vernier sensors 2/ project presentations
5. Week	Designing my own experience
6. Week	Project Presentations
7. Week	Testing designs and components

Research Setting

The activities and work for students' projects were conducted in the science classroom. Experiment tables and chairs where eight students could sit comfortably were in the classroom. Directly across from the front door is a teacher's desk and to the right of the desk is a smartboard. The classroom has a 2m x 1.5m window that can be opened. The south-facing classroom had four LED lighting panels 2.6 meters above the floor. The classroom was designed to look like a classroom without heating issues and had seating and a large bookshelf. Students sat in the classroom on sponge-backed chairs, and they sat so that they could see each other students faces.

Data Collection Instruments

Because the event and phenomenon must be studied in depth, diversification of data is necessary. Researchers have defined case study as an umbrella term that can include many data collection sources such as interviews, observations, questionnaires, documents, etc. (Çepni, 2014, p. 73). Semi-structured interview questionnaires (pre- and post-interview questions), rubrics (engineering and project design process skills, observer-teacher DPA), document review (EDP analysis form, students' project idea notes, Tinkercad program designs, design process screenshots, presentation files), student diaries and researcher diaries were used for data collection in the study. In this way, the researchers attempted to ensure a diversity of data that would allow for an in-depth analysis of the situation.

Data Analysis

Since the study was designed according to qualitative research methods and patterns, a content analysis of the data was performed. When there needs to be more information about the study topic, the researcher should conduct content analysis (Lauri & Kyngas, 2005). Elo and Kyngäs (2007) suggested using open coding, category building, and summarization methods for content analysis. The content analysis was used to show the cause-effect relationship and conduct an in-depth analysis. The answers to the questions were directly quoted, and no changes were made. Codes for related or similar questions were created based on the answers, and categories were formed from these codes.

Two experts selected by the unbiased assignment method were asked to code the data separately to ensure the internal reliability of the study. We used the intercoder reliability formula of Miles and Huberman (1994) for the reliability. The researchers coded the data and then sent it to another expert for coding. Similar codes that resulted in an agreement between the two coders were considered consensus, and dissenting codes were considered disagreement. The calculation was based on Miles and Huberman's (1994) formula (agreement/consensus + disagreement) * 100. The percentage of agreement on the preliminary interview form was 92%. The agreement rate on the final interview form was calculated as 91%. The reliability calculations above 70% indicate that the analysis is reliable (Miles & Huberman, 1994; Yıldırım & Şimşek, 2008). The duration of the pre-interview with the students totaled 81 minutes, the midterm interview lasted 24 minutes, and the final interview took a total of 112 minutes.

Before beginning the study, students were asked to assess their engineering and project design skills using a rubric and rate themselves using it. The researcher evaluated this rubric, in which students placed themselves on many skills, including identifying and researching the problem, solving the problem, integrating technology into problem-solving, product design for the solution, product presentation, and product redesign. At the end of the activities in this research, students were asked again to evaluate the same rubric. However, the principal researcher who collected the data and conducted the activities in this study did not complete the rubric to assess the students' project work because he needed to gain experience with students. The researchers did not meet the rubric to ensure the validity and reliability of the study.

The observer-teacher DPA was completed by teachers invited to teach during the third and sixth weeks of implementation. The compatibility of the forms completed by the three teachers was checked using Kendall's coefficient of agreement. "Kendall's W (Kendall's Coefficient of Concordance) is a nonparametric test that examines whether there is a significant degree of agreement based on a ranking by assigning the ratings of more than two raters to a group" (Can, 2019: 405). Kendall's coefficient of fit takes a value between 0 and 1, and the closer it is to 1, the higher the agreement is (Can, 2019). Calculations found a coefficient of agreement of .76.9% ($W=0.769$; $p < 0.05$) for the observations at the end of the third week. We found a rate of agreement of 75.3% ($W=0.753$; $p < 0$) for the observations. The students' notes on the projects and diaries were analyzed using the document analysis method, and direct quotes reflected the students' statements and project examples.

Validity and Reliability

Validity and reliability were considered in the study. For internal validity (credibility), expert opinions were obtained on each measurement tool, direct quotes were made from the interviews, and participants confirmed transcripts after the interviews. The researcher had long-term interactions with the participating students in all these processes. The interaction process included pre-interviews with the students, instruction on the 3D technologies and the robotic tools, and the teaching process. The instruments and data collection process were explained in detail for external validity. The method of the study was presented, as well as the characteristics of the study group and how it was selected. The study's process and the researcher's role were described. A voice recorder was used during the interviews with the students to avoid data loss to ensure internal reliability (consistency). In addition, during coding, results were reported directly without interpretation, while coherence of the coder was conducted under the control of two researchers. Data were appropriately discussed in the conclusions section, and data consistency was checked by two different researchers and controlled by a third researcher to ensure external reliability.

Findings

What is the current situation regarding using 3D technologies and robotic tools in science education before teaching?

Pre-teaching interviews were conducted with eight participants using a semi-structured interview form. The results of these interviews and direct quotes are provided below.

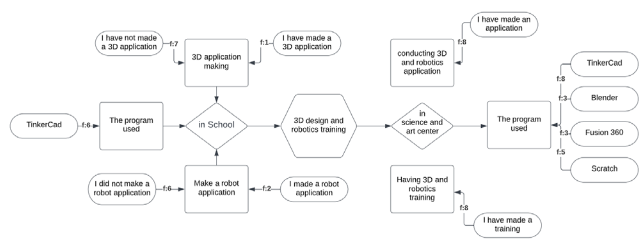

Fig. 3: Student Opinions On 3D Design and Robotics Education Before Teaching

As seen in the figure, the students' education level in 3D design and robotics is divided into three categories: 3D application, robotics application, and the program used in their school. Seven students (f:7) indicated that they did not make 3D applications in their school. One student (f:1) stated that they made 3D applications in their school. Student Nur[B2D] said, "*Right now, it is not there yet, but my technology design teacher knows I use Arduino, and he wants to do a design with me*," while student Mert[B1D] said, "*Yes, we do; we learned circuits with Tinkercad*." Considering these views, we can conclude that most students do not use either technology in their schools.

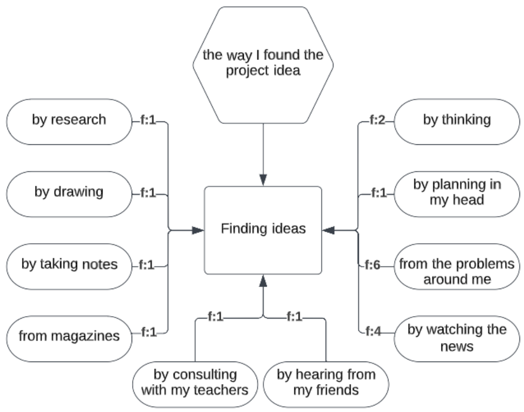

Fig. 4: Ways For Students to Find Project İdeas Before Teaching

As seen in the figure, the results show that the students generated project ideas from the problems in their environment and used their thoughts about the problems. While Mert[B1D] stated, "*I used the problems that come up when I look outside and were demonstrated about the problems on TV.*" Another student, Nur[B2D], indicated, "*I first look at the problems I faced in life,*" Aybüke[B2D] expressed this: "*I think things from my mind or from what I have experienced*." These results show that they used the problems and news in their environment to develop project ideas and used different ways when coming up with ideas.

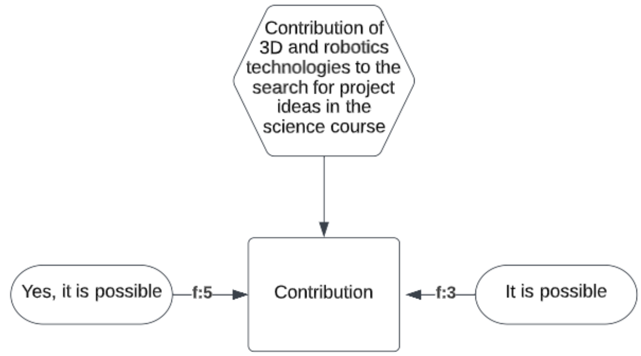

Fig. 5: Students' Opinions On The Contribution of 3D and Robotics Technologies to Project *İdentification* Before Teaching

The results in figure 5 show that most students strongly believed that 3D and robotics technologies helped in finding a project in the pre-science course is five (f:5). In contrast, only three students believed that 3D and robotic technologies contributed to generating project ideas (f:3). Regarding the situation, Aylin[B1D] indicated "*Hm, we can learn better what the parts are for.*" Önder[B2O] stated, "*It is not enough to just have the idea, you have to implement it, and for that, you need much science knowledge*." Mert[B1D] said, "*Maybe it will be beneficial if I learn how to use the sensors I made here to develop project ideas in school*." These results reveal that students generally indicated that using these two technologies in science class helped them develop a project idea (Figure 6).

As seen in Figure 6, students think more when solving the problem before applying it and acting according to their planned solutions. In this context, Aybüke[B2D] said, "*I mean, I think from the other side*," while Remzi[B2Ö] expressed his opinion: "*I think about which way I can go first*." Okan[B2D], on the other hand, described, "*I design more in my head how it will be*."

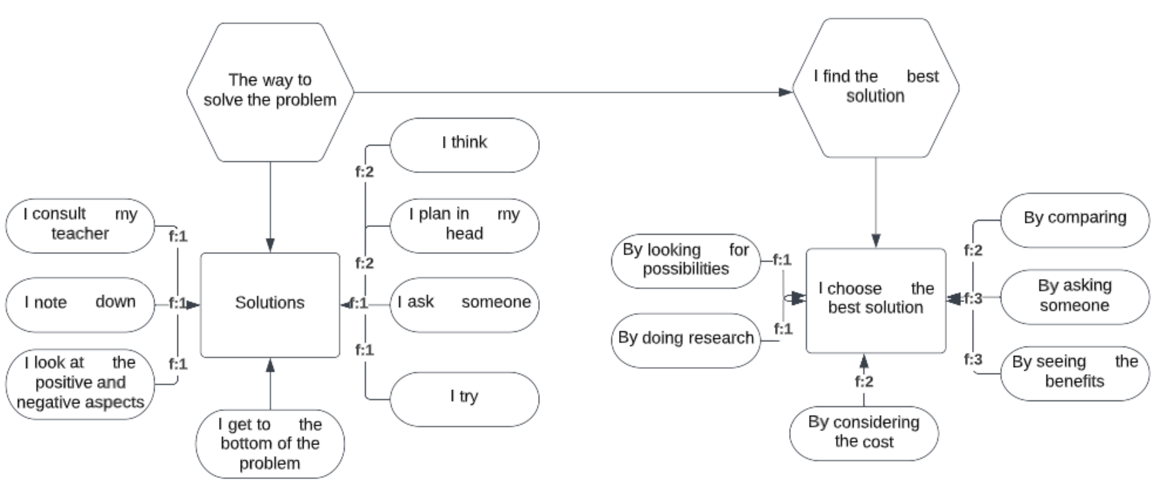

Fig. 6: Ways to Find a Project İdea Before Teaching

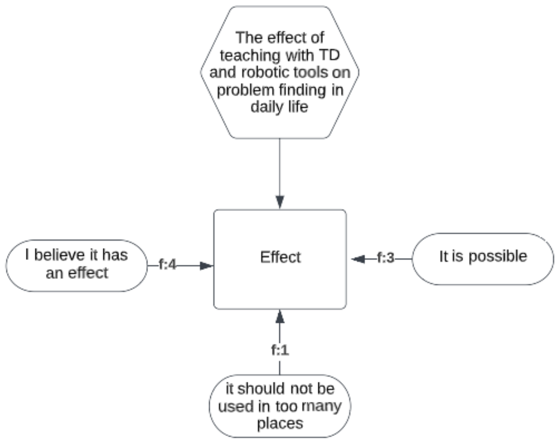

Fig. 7: The Effects of 3D And Robotic Technologies on Finding Daily Life Problems Before Teaching

When examining Figure 7, four students (f:4) indicated that they believed that teaching about 3D technologies and robotics tools in school had an effect, while three students (f:3) stated that it might. One student thought that the widespread use of these technologies could cause problems in the future. Regarding the situation, Nur[B2D] answered, "*Yes, when I find a problem, we develop a project for it, and in this project, we can use robotic tools and 3D design*." Another student, Remzi[B2O'], said, "*Yes, for example, I designed something with some 3D programs against some problems*." Based on these findings, we can conclude that the students think using these two technologies helps to find new project ideas.

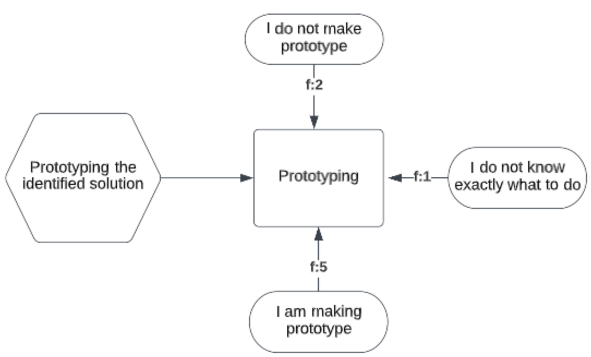

Fig. 8: Students' Views on the Situation in Prototyping the Solution *İdentified* Before the Teaching

The results in Figure 8 show that five students indicated that they created a prototype, two students did not, and one suggested that s/he needed to learn what to do precisely. While student Önder[B2Ö] said, "*I made drawings of the models*," Aybüke[B2D] indicated, "*For example, I prepare them on a model or a poster.*" However, none of the students said they prepared their prototypes in a 3D design program or using robotic components. This result can be interpreted as the students not using these technologies when creating a prototype.

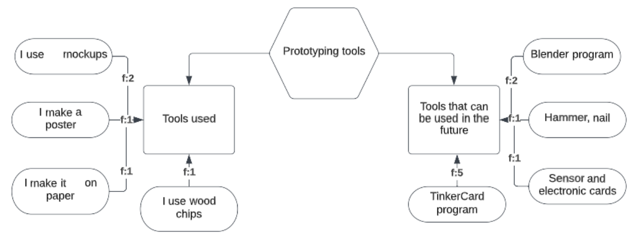

Fig. 9: Prototyping Tools For Problem-Solving Before Teaching

As presented in Figure 9, we found two categories of tools that students used when preparing prototypes before teaching in this study. The responses indicated that the students used various devices such as models, posters, drawing paper, and pieces of wood to prepare the prototype. While Aybüke[B2D] answered, "*I prepare it on a model, for example*," Mert[B1D] said, "*I did something with wood.*" In the category of tools that can be used in the future, students mainly indicated that they could use the program TinkerCad. Two students (f:2) indicated that they could prepare it using the Blender program, while another student (f:1) indicated that they would use sensors and electronic cards. Another student (f:1) suggested they could use tools such as hammers and nails. The results in this category show that the students mainly indicated that they could use the program TinkerCad.

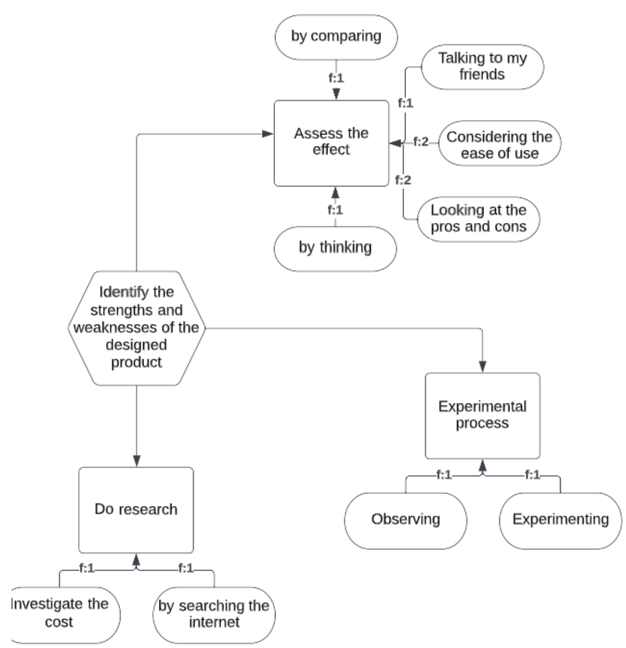

Fig. 10: Students' Views on Determining the Strengths and Weaknesses of the Designed product before the teaching

The results in Figure 10 show that student responses were grouped into three categories: doing research, observing/ conducting an experiment, and looking at the effect to determine the designed product's strengths and weaknesses before teaching.

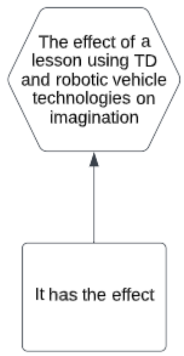

Fig. 11 Students' Views on the Effects of 3D And Robotics Technologies on İmagination

As can be examined in Figure 11, all students indicated that the course that covered 3D and robotic technologies influenced their imagination. Regarding this result, Aylin[B2D] stated, "*Yes, the course helped me develop my imagination by thinking about how I can invent something new by combining them.*" Another student, Aybüke[B1D], said, "*I think because I can do better things when I use 3D tools, for example, when I draw on a normal square. ...* ". Another student, Önder[B2O], emphasized, "*Yes, because an experiment and a construction we made with coding tools can increase our imagination, and we can think in newer projects*." These results show that all students think that two technologies used in this research positively influenced their imagination.

Case After Teaching

This section presents the results regarding developing students' engineering design and project design skills using robotic tools and 3D technologies.

How do students' skills using robotic tools and 3D technologies develop after class?

The Development of Engineering Design Process Skills

Students completed a rubric before the teaching to assess their skills related to the engineering design and project design process. The rubric was intended to identify students' skills in problem identification, problem-solving, integrating technology into the problem, product design for the solution, product presentation, and product redesign. Student responses were analyzed for each process.

Table 3. *A comparison of students' engineering and project design skills before and after teaching*

	Before teaching						*After teaching*					
Skills	Excellent	Very good	Good	Medium	Should be improved	Not observed	Excellent	Very good	Good	Medium	Should be improved	Not observed
Identification and search of the problem	f	f	f	f	f	f	f	f	f	f	f	f
I set myself a problem for a problem I encounter in daily life	2	3	3				4	4				
In formulating the problem, I connect the problem and the science subject.	2	1	3	2			2	3	3			
I formulate the problem as a research question		4	2	2			3	3	2			
I establish a relationship between cause and effect in relation to the problem		4	2	2			5	2	1			
I research the problem	3	2	1	1	1		4	1	3			
Solution of the problem												
I offer ideas for solving problems	2	4	2				5	3				
I determine the appropriate solution to the problem		4	2	2			5	3				

	Before teaching						*After teaching*					
Skills	**Excellent**	**Very good**	**Good**	**Medium**	**Should be improved**	**Not observed**	**Excellent**	**Very good**	**Good**	**Medium**	**Should be improved**	**Not observed**
I discuss my ideas for solutions with my friends.	1	5	1			1	3	2	3			
I defend my ideas about the solution	4	1	2	1			4	1	3			
I create a plan for the solution		4	2	2				4	4			
Technology integration in problem-solving												
I use 3D technology in problem solving	2	3			1	2	3	3	2			
I use at least one robotic tool in problem solving	1	2	2	1	1	1	6	2				
I express the importance of robotic tools in problem solving	1	3	1	3			4	3	1			
I express the ease provided by 3D technologies in problem solving.	2	1	3	2			3	3	2			
Solution for Related Product Design												
I design suitable products to solve problems	2	3	2	1			4	3	1			
I obtain numerical data from the robotic tools he uses in his product.		3	1	2		1	4	1	3			
I pay attention to 3D design and modeling processes when I design a product.	2	4	1	1			3	3	2			
I will test if the product works	5	3					4	2	2			
Product Presentation												
I present my product to my other friends	5	3					3	3	2			
I explain how my product solves the problem		5	3				5	2	1			
I tell my friends about the advantages of the product	3	4				1	5	3				
I tell my friends about the limitations of the product	2	4	2				4	3	1			
Product Redesign												
I develop new proposals for the product I have designed	1	5	2				2	3	3			
I reflect the proposals to the product design	3	3		2								

Table 3 shows an analysis of students' answers in the problem identification and research phase before teaching were between the "needs to be developed" and "excellent" levels. After instruction, the results were between the "good" and "excellent" levels. About this finding, Önder[B2O], for example, stated, "*The sensors we learned in the courses contributed positively to our projects so that we can produce more projects in this way*."

Students' responses regarding the problem-solving phase before teaching are between the "not observed" and "excellent" levels. One student (f:1) did not have these skills. After teaching, the results show the "good" and "excellent" categories. This result indicates that the students' skills did develop after teaching. Regarding this situation, Nur[B2D] said, "*When I had a project idea at home, I thought I could do it, but I could not decide how to do it, what tools to use. I was always confused, but now I have learned*.".

Regarding technology integration in problem-solving, students' pre-teaching responses ranged from "not observed" to "excellent" In contrast, post-teaching results went from "good" to "excellent." In the problem-solving process category, three students (f: 3) rated their skills in using 3D technologies and robotic tools at the "developable" level before teaching. Considering these results, we conclude that students' technology integration skills improved after the instruction in this study. For example, Remzi[B2Ö] said, "*When I think about* *the contribution of sensors and how I can solve a problem, sensors come to my mind*.". Eren[B2D] indicated, "I *have started doing different projects with the sensors*" Okan[B2D] stated, "*The technology integration has contributed a lot, especially because I can make better designs with TinkerCad*."

Regarding the product design phase, students' responses regarding the solution before teaching were distributed between the "not observed" and "excellent" levels. After the teaching, these levels changed to "good" and "excellent." The students started to design appropriately for the problem. They also obtained good numerical data from the robot tools, and they considered the 3D design processes. For example, Önder[B2Ö] indicated, "*I prepared it through the sensors we learned with the Lego Mindstorm card, and it was beneficial to use the 3D printer and robot components at the same time in the prototype.*" Another student, Okan[B2D], expressed, "*The programs contributed completely. Because I used 3D programs to transfer them to the 3D printer*."

At the product presentation stage, students answered at the "good" and "excellent" levels for their skills, but this finding remained the same before teaching. After teaching, five (f:5) students answered "excellent" to the statement "I present the product I presented to my other friends" before teaching, while three (f:3) students did so after instruction. This result shows that students did not make presentations to their friends during the presentation to the jury. This result may stem from students presenting in front of the jury. The table shows that the "very good" and "excellent" responses increase for other skills in the same category. Student Okan[B2D] commented, "*The presentation and the suggestions I received during the presentation helped me a lot.*" ÖnderB2Oe commented: "*I made the projects I did with these suggestions one or two times easier.*" This result was expressed in the diary of student Aybüke[B2D] on 07/02/2022 as follows, "*The suggestions of my friends and the jury caused me to make some changes to my designs.*"

The results of the redesign of the products show that the students' responses before the teaching were between "moderate" and "excellent." After the teaching, the results showed that the students' skills increased from "very good" to "excellent." This result means that students redesigned the products in light of the suggestions they received. From this result, we conclude that students developed their skills of presenting problems from daily life and making a connection to the science course, creating a research question, exploring the problem, and establishing a cause-effect relationship related to the problem while doing so.

The Development of Students' Project Design Process Skills

Table 7 shows how students used robotic tools and 3D technologies in science lessons before and after developing the teaching. Table 7 includes students' project ideas before the teaching and students' ideas after the teaching.

Table 4 shows five categories regarding project ideas before implementation. These are disabled, environmental problems, animals, traffic accidents, theft, and health. Three students (f:3) for the disabled and two (f:2) for the environmental problem category developed a project idea. One student proposed a project idea for each of the other categories. After implementation, the project ideas were discussed in twelve categories. After implementation, students' new categories in their projects were: everyday life, natural disasters, heating systems, plants, transportation, and energy. While one project was proposed in the health category before teaching, eleven projects were developed after instruction.

Project ideas before teaching					**Project ideas after teaching**				
Themes	**Category**	**Code**	**Student**	**f**	**Themes**	**Category**	**Code**	**Student**	**f**
	Disabled people	Blindfolded	Mert[B1D] Remzi[B2Ö]	2	**Project idea**	**Disabled people**	Public transport assistant for visually impaired people	Eren[B2D]	1
		Physically disabled	Eren[B2D]	1					
	Environmental problems	Burning of forests	Önder[B2Ö]			**Environmental problems**	Prevent water waste	Aylin[B1D]	1
		Water poisoning	Okan[B2D]	1			Air quality	Aybüke[B2D]	1

Project idea	Animals	Abandoned animals	Nur[E2D]	1
	Traffic accidents	Talking traffic light	Mert[E1D]	1
	Theft	Theft of objects	Aybüke[E2D]	1
	Health	Measuring Fever of Patients with Covid	Aylin[E1D]	1
	Animals	Measuring the pH of fish water in the aquarium	Aylin[E1D]	1
	Traffic accidents	Prevent traffic accidents	Aybüke[E2D]	1
		No more sleeping drivers	Aybüke[E2D]	1
	Theft	Pillows that notify the thief	Önder[E2D]	1
		Safe mat	Okan[E2D]	1
	Health	Healthy canister	Aybüke[E2D]	1
		Upright chair	Aybüke[E2D]	1
		Stove poisoning	Remzi[E2D]	1
		Natural gas poisonings	Önder[E2D]	1
		Poisoning through the chimney	Önder[E2D]	1
		Gas explosions	Mert[E1D] Eren[E2D]	2
		Chair for sitting upright	Remzi[E2D]	1
		Uvb curtain	Nur[E2D]	1
		Healthy skin	Nur[E2D]	1
		No more sunburns	Eren[E2D]	1
		Protect the health of the eyes	Aylin[E1D]	1
	Everyday Life	Toy Collector	Aybüke[E2D]	1
		Safe pressure cooker	Okan[E2D]	1
		No soaking at night	Aybüke[E2D]	1
		Solar cell bank	Aylin[E1D]	1
	Natural disasters	Earthquake detector	Nur[E2D]	1
	Heating systems	Sun tracker	Aylin[E1D]	1
	Plants (Agriculture)	Keep plants from withering	Önder[E2D]	1
		Moisture meter flower pot	Okan[E2D]	1

	Intelligent watering system	Aybüke[B2D] Mert[B1D]	2
Transport	Gas pressure in hot air balloons	Aylin[B1D]	2
Energy	UV controlled solar charger	Aylin[B1D]	1

Table 5: A comparison of technologies used by students to solve everyday life problems

Students	*Number of project ideas*	*Number of projects with 3D technologies*	*Number of projects with robot tools*	*Number of integrated projects*
Aybüke[B2D]	**8**	8	8	**8**
Aylin[B1D]	**7**	6	7	6
Eren[B2D]	**3**	2	3	2
Mert[B1D]	**2**	1	2	1
Nur[B2D]	**3**	2	3	2
Okan[B2D]	**3**	3	3	3
Önder[B2Ö]	**4**	4	4	4
Remzi[B2Ö]	**2**	2	2	2

The results show that Aybüke[B2D] submitted eight (f:8) project ideas and used 3D design and robotic tools that were integrated with solving everyday problems. Aylin[B1D], who submitted seven (f:7) project ideas, did not use 3D design tools in one of her projects. Aylin[B1D] used robotic devices to find solutions to everyday problems and integrated these tools into all six projects (f:6). Eren[B2D] proposed three (f:3) project ideas. It did not use any 3D design technologies in one of these projects. He used robotic tools in all his projects and integrated them into two projects. Mert[B1D] had two (f:2) project ideas, and while he used a robotic vehicle in both projects, he made a 3D design in one of his projects. He included one project in the integration process. Nur[B2D] submitted three (f:3) project ideas and integrated them into two projects. Okan[B2D] presented three (f:3) project ideas and integrated 3D technologies and robotic tools into his projects. ÖnderB2O proposed four (f:4) project ideas and tried to solve daily life problems by integrating 3D technologies and robotic tools into all his projects. Finally, Remzi[B2O] presented two (f:2) project ideas. These results reveal that students generally integrated 3D technologies and robotic tools into their projects. Moreover, students frequently used 3D technologies and robotic tools to solve everyday life problems in their projects.

Discussion And Conclusion

Before Teaching

The results before implementing teaching in the study showed that students did not use the 3D technologies and robotic tools separately in their schools. The results also showed that they did not conduct project works by integrating the two technologies. Students generally used the problems for projects they had heard about or noticed in their environment. Before the teaching in this research, we found that students followed a mental process to find a solution to the problem, such as thinking, designing in their minds, and developing different solutions. Before teaching, the best methods students used were to evaluate the usefulness, ask someone, compare, and evaluate cost (see Figure 7). In addition, this study also showed that not all students used 3D design technologies in their projects when preparing prototypes before applying them. This finding may be due to students' perception of the prototyping process as more of a paper design. We found that students revealed the strengths and weaknesses of their projects by conducting research, observing the effects of the study, and conducting experiments to determine the strengths and weaknesses of the designed product before teaching. The results also showed that most students had no presentation experience before teaching.

After Teaching

The results showed that students could present problems from daily life and relate them to the science course, create a research question, investigate the problem, and establish a cause-and-effect relationship to the problem. After teaching, we found that students developed skills in presenting ideas to solve problems, determining appropriate solutions, discussing their ideas with classroom mates, and creating a solution plan. For example, Sen et al. (2021) concluded that students who used robotic tools developed skills such as association, problem determination, problem-solving, and questioning. The results of this study are consistent with those of Sen et al. These results could be because students had the opportunity to discuss and create solution plans with their friends. The results are also similar to those of Özel (2018), who found that integrating robotics into the eighth-grade curriculum increased students' collaborative learning skills and motivation.

The findings revealed that students' technology integration skills improved after the teaching. Through activities in this study, students could use at least one robotic tool by incorporating 3D-integrated technologies into their studies. In the product design of EDP, we found that students started to design for the problem, obtained good numerical data from robotic tools, and sought to implement 3D design processes. Regarding the product presentation results, the results show that the students' presentation skills improved due to their presentations to the jury. Regarding the "redesigning the product" step of the EDP process, we found that students reviewed their designs following the suggestions received in the presentation and discussed them in the redesign process. As it is well known, designing the learning and teaching process based on a constructivist perspective is essential. Thus, students can think multidimensionally and develop solutions to daily life problems in various fields. In the project process, students are expected to develop solutions to problems along with computational thinking skills to support more meaningful learning objectives (Severance, Miller & Krajcik, 2024). While the projects identified by the students were divided into six categories before the teaching, this number increased to twelve categories after the teaching. The number of students' prototype designs increased after teaching. It is also noted that students developed many project ideas, especially on health. In general, it was found that students' topics related to problems of daily life and problems related to these topics became more diverse, and the number of project ideas increased. This situation is similar to Çakır and Mistikoğlu (2021), who positively reported the benefits of using 3D technologies for students.

All participating students presented more than one project design. Two students completed the process with two project designs. Other students presented three or more project designs. It was found that students used robotic tools in all the projects they designed. This finding shows that students could integrate the robotic tools into their project processes and internalize the integration processes. As a result, they started to use mainly 3D technologies and robotics tools, properly integrating both technologies, which increased their interest and curiosity to create new projects. The results showed that students developed by learning the 3D technologies and robot tools and using different technologies in their projects. Karakuş and Bolat (2020) found that gifted students produced many ideas on various topics. This supports Tilden et al. (2024) suggestion that robots may have potential for use in educational settings. The study found that students identified problems in daily life more easily and could develop solutions. Sağat and Karakuş (2019), in their research to determine the project performance of gifted students, found that remedial students performed exceptionally well when they presented project ideas from daily life related to science. In a study by Li et al. (2016) on fourth graders' performance in activities with Lego kits, they found that students' science achievement and problem-solving skills improved during the EDP process. They indicated that students considered some points such as cost-effectiveness, comparison with other projects, feasibility, and utility. Similar to these findings, Mentzer (2011) emphasized that understanding the problem is related to the limitations of the problem and the determination of the criteria.

The results show that students' design skills developed as they created prototypes using 3D design programs and integrated robotic and 3D technologies into the process. The study results are similar to those of Güneş et al. (2020). They found that printer technologies were helpful in manufacturing products, recognizing mistakes, solving problems, and adapting design ideas to real situations. Coşkunserce et al. (2017) concluded that students using robot kits could identify and control mechanical and electronic components. Similar studies in the literature report that students' motivation increases (Koç Şenol & Büyük, 2015; Barker & Ansorge, 2007). Our findings about the visualizations of the prototypes students created revealed that students who used 3D design were excited, happy, and enthusiastic during the presentation. Our results are consistent with the findings of Tatlısu (2020), who found that robotic teaching students felt happy and excited. After the presentation, it became clear that they were primarily considering the panel's suggestions and incorporating their classmates' opinions into their projects. Studies in the literature show that students involved in the design process share their ideas (Brunsell, 2012; Hynes et al., 2011). The findings demonstrate that students' imagination did develop after using these skills.

Suggestion

The results show that science education supported by robotics tools and 3D technologies positively contributes to developing engineering and project design skills. The results also show that 3D technologies and robotics tools are essential for students to build projects for problems. Activities integrating these technologies with an interdisciplinary approach in the classroom and workshops are expected to contribute positively to student development. Hands-on and collaborative activities in schools for gifted students can help improve their problem-identification skills. We suggest that further studies be conducted to understand how higher-order thinking skills develop through 3D technologies and robotic tools. Teachers and researchers who wish to use 3D printing technologies and robotic tools in their classrooms can use these technologies for educational purposes. Activities can be developed to engage student interest and demonstrate that these tools can easily be used in projects to solve problems.

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