A STEM ACTIVITY FOR GIFTED STUDENTS: BIODEGRADABLE SMART PACKAGING DESIGN THROUGH PHYSICAL COMPUTING[1]

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ABSTRACT

The study aims to present how to apply a STEM activity in which physical computing principles and computational thinking processes are used as a differentiation practice to be used in the education of gifted students. In the activity, the students designed smart packaging that will provide healthy long-term storage of foods to solve the greenhouse gas emission problem caused by intensive plastic production. The activity was carried out with eight gifted students studying in 7th -9th grades. The students investigated the factors that would reduce greenhouse gas emissions and synthesized biodegradable polymers during the inquiry process. In the engineering design process, they determined the most suitable solution for packaging design in the polymer synthesis they carried out using different plant extracts with antibacterial properties. They developed a smart packaging design using physical computing in this process. During the STEM activity, the students used computational thinking, engineering design, and inquiry process.

Keywords: STEM education, gifted students, physical computing, computational thinking.

ÖZEL YETENEKLİ ÖĞRENCİLER İÇİN STEM ETKİNLİĞİ: FİZİKSEL PROGRAMLAMA YOLUYLA BİYOLOJİK OLARAK PARÇALANABİLEN AKILLI AMBALAJ TASARIMI

ÖZ

Bu çalışma, özel yetenekli öğrencilerin eğitiminde kullanılmak üzere bir farklılaştırma uygulaması olarak fiziksel programlama ilkeleri ve bilgi işlemsel düşünme sürecinin kullanıldığı bir STEM etkinliğinin nasıl uygulanacağını sunmayı amaçlamaktadır. Etkinlikte öğrenciler, yoğun plastik üretiminden kaynaklanan sera gazı emisyonu sorununu çözmek için gıdaların uzun süre sağlıklı bir şekilde saklanmasını sağlayacak akıllı ambalajlar tasarladılar. Etkinlik 7-9. sınıflarda öğrenim gören sekiz üstün yetenekli öğrenci ile gerçekleştirildi. Öğrenciler, sorgulama sürecinde sera gazı emisyonlarını azaltacak faktörleri ve biyobozunur polimerleri sentezlediler. Mühendislik tasarım sürecinde antibakteriyel özelliklere sahip farklı bitki özleri kullanarak gerçekleştirdikleri polimer sentezinde ambalaj tasarımı için en uygun çözümü belirlediler. Bu süreçte fiziksel programlamayı da kullanarak akıllı ambalaj tasarımı gerçekleştirdiler. STEM etkinliği sırasında öğrenciler bilgi işlemsel düşünme, mühendislik tasarımı, sorgulama sürecini kullandılar.

Anahtar kelimeler: STEM eğitimi, özel yetenekli öğrenciler, fiziksel programlama, bilgi işlemsel düşünme.

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INTRODUCTION

The interest in Science, Technology, Engineering, and Mathematics (STEM) education is increasing day by day with the perspective of innovation, creativity, and problem-solving. The need for a STEM workforce, especially in the 21st-century digital age, makes STEM education the focus of attention of researchers and educators (Kayan-Fadlelmula et al., 2022; Sarı et al., 2020). STEM education is important for students to understand the real world, explore, question, experience solutions to natural world problems, and develop 21st-century skills (Asghar et al., 2012). In the literature, it has been determined that STEM education improves students' motivation toward mathematics and science and their attitudes toward STEM (Baran et al., 2015; Yoon et al., 2014), increases their academic success (Wallace et al., 2015), enables them to produce ideas collaboratively (Montgomery & Madden, 2019; Yıldız & Ecevit, 2022), and contributes to the development of career interests (Sarı et al., 2018). In addition to these studies with students at normal ability levels, positive effects of STEM education are observed in studies conducted with gifted students. There are findings that gifted students improve their scientific attitudes (Kim & Choi, 2012), increase their interest and self-efficacy in STEM fields (Almarode et al., 2014; Burt, 2014), positively affect their self-confidence and career knowledge (Willis, 2017), increase their academic success (Young et al., 2017) and improve their engineering skills (Ayverdi & Öz Aydın, 2022).

Gifted students have important characteristics and skills such as being curious, applying the information they have acquired in mathematics and science, transferring knowledge to different situations, analytical thinking, problem-solving, and creativity. These features are important skills that students use or develop in STEM education (Mann et al., 2011). Hence, it is essential to include STEM education in gifted students to raise individuals who contribute to productive, economic, and social developments needed by countries. It can be stated that directing gifted students to these areas will be effective considering the goals of STEM education to raise productive individuals who solve problems and think creatively and innovatively.

According to the literature, differentiation should be made in the education of gifted students so that they can use their potential at the highest level and be beneficial to themselves and their environment (Bennett-Rappell & Northcote, 2016; Kaçmaz & Kılıç, 2019). Differentiation is the teacher's ability to respond to students' needs and provides flexibility in terms of arranging time, choosing materials, grouping students, expressing what has been learned, and evaluating learning (Davaslıgil, et al., 2004). The main principle of the activities developed for gifted students is that their learning experiences are qualitatively different from the general teaching activities developed for all students. Here, the qualitative difference is the differentiation by the characteristics and needs that make gifted students special (Koksal & Kılınc, 2022). This differentiation is related to the development, learning speed, cognitive differences, and motivations of gifted students. In STEM education, differentiation can be made by the potential of gifted students in the process of integrating engineering and technology with other disciplines. In this process, content differentiation can be made by using different methods, techniques, and technologies in line with students' interests, prior knowledge, and learning styles, and innovative product developments can be achieved by developing high-level thinking skills (Şahin, 2018). Differentiation can be made by using physical computing in STEM activities. In physical computing, which includes creativity and engineering design process, information from computer science, engineering, and different disciplines are applied with an interdisciplinary approach, and interactive designs and applied projects are realized in the real world (Juškevičienė et al., 2021; Sarı et al., 2022). Physical computing activity, in which hardware such as sensors, leds, and programming components such as creating algorithms and code writing are brought together, can be considered as an activity that requires high mental functions, enables people to organize and build their environment, and brings social and intellectual functions together. Computational thinking (CT) can be developed through physical computing activities, which are preferred in recent years to attract and motivate students in STEM education (Juškevičienė et al., 2021). CT, as a way of thinking for solving problems, includes problem-solving processes such as defining the problem, determining the solution steps (creating algorithms), collecting and organizing data, and creating patterns and models (Sadik et al., 2017; Wing, 2008). A well-structured physical computing activity can include these processes and thus contribute to the development of CT. CT is a common reflection of creativity, algorithmic thinking, critical thinking, problem-solving, collaborative thinking, and communication skills (Korkmaz et al., 2017). In addition, some tendencies and attitudes such as coping with complexities, persistence in dealing with difficult problems, tolerance for ambiguities, coping with open-ended problems, working in cooperation and communication with others to reach a common goal and solution are stated as the basic dimensions of CT (The International Society for Technology in Education & the Computer Science Teachers Association, 2011). These attitudes and tendencies are the characteristics of gifted students (National Association for Gifted Children, 2022). Therefore, with a learning environment that will support the development of CT with the STEM approach and physical programming principles, it can be ensured that gifted students can use their potential more efficiently.

Arduino tools were used in the physical computing process in this study. Arduino microprocessor is one of the most preferred tools for physical computing with its cheap and flexible structure (Sarı et al., 2022). Although this processor uses a text-based programming language, it has been reduced to teaching programming using visual coding blocks recently (Fidai et al., 2020). This feature offers an environment where different age groups and those who are new to programming can create their designs. Original designs can be made by adding various sensors that can detect physical environment properties to the Arduino processor, and thus contribute to STEM education (Wang et al., 2016).

The Aims and Importance of the Activity

The content of the activities and the experiences of the teachers are essential in achieving the goals of STEM education for gifted students. Teachers need exemplary STEM activities with the necessary differentiation to contribute to the increase in the potential of gifted students in their classrooms (Ayverdi & Öz Aydın, 2022). However, examples of such activities are limited in the literature (Morris et al., 2019; Özçelik & Akgündüz, 2018). There are some STEM activities related to packaging material design in the literature (Sakon & Petsangsri 2021; Seebut et al., 2023). In these activities, students focused on designs that can be used for packaging purposes, using ready-made materials such as paper. In our activity, unlike other STEM activities, students developed a product that met certain criteria for food packaging and used the materials they produced instead of ready-made materials. In this context, the study aims to present a STEM activity in which physical computing principles and CT processes are used as a differentiation application to be used in the education of gifted students. The activity was implemented by one of the researchers working in an institution providing education to gifted students in Turkiye.

The Learning Objectives

This STEM activity aims to engage gifted students in creating a biodegradable smart packaging design by integrating basic knowledge in the fields of polymer chemistry and global climate change with basic knowledge in technology, engineering, and mathematics. The students will also learn information about food spoilage and how to store foods safely for a longer time. The activity was designed and implemented as a differentiation activity to meet the learning needs of gifted students. These needs were: focusing on big ideas, adapting to learning pace, difficulty, and interest, suitable for individual learning, and enabling alternative ways (Tomlinson, 2001). Learning and innovation skills from 21st-century skills in the activity include the skills determined by Partnership for 21st-Century Learning (2019). Scientific process skills such as observing, measuring, classifying, data recording, forming hypotheses, constructing experiments, determining, changing, and controlling variables are integrated into the experimental part of the activity. The activity learning objectives include Science, Technology and Design, and Mathematics standards of the curricula applied in Turkiye Science and Art Centers (Ministry of National Education [MoNE], 2022). Some of the learning objectives were taken directly from the curriculum while some of them were rewritten by taking them to higher levels. For example, the objective "Designs an intelligent system application that works with temperature, humidity, pH, etc. sensors" was at the applying stage in the curriculum. This learning objective was raised to the stage of creating with the statement "Designs a unique smart system application that works with temperature, humidity, pH, etc. sensors". Engineering objectives were selected from the Next Generation Science Standards (National Research Council [NRC], 2013). The Common Core State Standards (CCSS) for mathematics (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010), to which the NRC (2013) standards are related, were also taken into consideration in the design of the activity. Some additional learning objectives were also written specific to the activity. All learning objectives are given in Appendix 1.

ACTIVITY IMPLEMENTATION

Materials

The materials were provided by the school. They include the following items:

- graduated cylinder,
- analytical balance,
- pure water,
- glycerine,
- sodium alginate,
- calcium chloride,
- organic materials that can be used in the synthesis of biodegradable materials (e.g., plant extracts),
- Arduino uno board,
- Arduino tools such as gas sensor, temperature sensor, and other tools to use,
- metal container,
- silicone, and silicone gun.

Procedures

The activity was implemented with eight gifted students. Students worked in two groups. They were in grade levels ranging from seventh to ninth. Two of the students were male, and six of them were female. The activity was held in a public institution in Turkiye that provides education to the gifted in line with their interests and abilities. The students have studied at this institution for three years. The students engaged in scientific research processes and scientific research experiences before the activity. The activity was implemented as 16-lesson hours (16 x 40 min.).

The activity started with a real-life problem that defined the context of the STEM activity. The teacher shared the plastic production and usage data in the world, and the students discussed the impact of this process on climate change. The greenhouse gas effect of plastic packaging was presented to the students as a real-life problem, emphasizing the packaging industry, one of the most widely used areas of plastics. Students investigated the factors that would reduce greenhouse gas emissions caused by the production of plastics used in food storage. They completed the task of designing biodegradable smart packaging by conducting the inquiry and engineering design process. Students used the “Student Worksheet” to record their experimental data in the activity (Appendix 2). In addition, they carried out their engineering designs by the steps that included the "Engineering Design Process" (Appendix 3). They developed an intelligent system using physical computing with an Arduino microcontroller in this process. After the students tested their designs, they corrected the deficiencies and worked for improvement. The activity implementation process is detailed below.

Presenting the Problem

The teacher drew attention to the impact of plastic production and use on climate change by sharing the information given in summary under the title *“Plastic production, use, and its impact on climate change”* (Appendix 4). (5 min.). The students discussed the place of packaging in our lives, individual use of plastic packaging, and its effects on climate change:

> Teacher: Where do you use the packaging most?
> Several Students: Gift packaging;
> Food packaging;
> Water;
> Clothes;
> Detergent packages.
> Teacher: What is your preference and frequency of use of plastic packaging?
> Student 1: I use it in all prepared foods, teacher.

Student 2: I use it in the food I buy at school every day.
Student 3: I try not to use it too much. It is harmful to the environment.
Teacher: What kind of damage does it have to the environment?
Student 3: When left in the environment, it harms as garbage.
Student 4: Fossil fuels are used in production.
Teacher: What is the harm of fossil fuels?
Student 4: It causes greenhouse gases to spread to the environment.

Afterward, the following problem situation was presented to the students: *What can we do to reduce greenhouse gas emissions from the materials used in the transportation and storage of packaged foods we consume (for example, chicken)? What do you think about this issue as individuals sensitive to climate change? What is expected of you in this study is to design smart packaging that will reduce greenhouse gas emissions caused by the production of plastic used in food storage, allow food to be stored safely for 15 days, be biodegradable, economical, and at the same time provide information about the environment (ambient temperature, gas, pH, humidity, etc.) in which the food is located.*

The problem situation was discussed with the students, and they were asked to write down the features that a solution-oriented design should have. Thus, it was ensured that they determined the criteria and limitations of their designs (10 min.).

Inquiry Process

The students were allowed to make inquiries and access the necessary information for a solution at this stage. First, the problem was discussed, and research questions were created about the research on what to know for a solution. The following research questions were created by the students under the guidance of the teacher. (10 min.):

- *What are the causes of spoilage of packaged foods?*
- *How can we understand that foods such as chicken are spoiled?*
- *What can be done to prevent food from spoiling?*
- *What materials can be used for the production of biodegradable packaging?*
- *How does the production process of biodegradable packaging take place?*
- *How can you be informed about the spoilage of packaged food in your hand without opening the package?*

Then, the students conducted a literature search under the guidance of teachers using addresses such as thesis, google academic, and Dergipark (25 min.) (Photograph 1). The students concluded that the causes of spoilage of packaged foods were microorganisms such as bacteria and viruses during the research process they carried out in line with the research questions. Afterwards, they read the literature (Kılıç et al., 2022) that they could determine the spoilage of the food from the smell and microorganisms on the food. Learning that different packages can be used to preserve foods for a long time without spoiling, the students determined the polymers used for this purpose. They comprehended that the antimicrobial property is important to prevent food spoilage.

Photograph 1. Students Doing a Literature Review in the Lab

The teacher guided the students to reach the right resources in this process. Students researching biodegradable polymers that can be used as food preservation materials encountered materials such as hydrogel and bioplastic. Considering the advantages and disadvantages of these materials, they decided to produce hydrogels for food preservation.
Teacher: What are the materials used to keep foods intact for a long time?
Student 5: Hydrogels.
Student 1: Bioplastics.
Student 3: Paper bags.
Student 6: Synthetic plastic packaging.
Teacher: Which materials among these serve our purpose? Which is/are

advantageous?

Student 7: Since synthetic plastics are destroyed in nature in a long time, they do not serve our purpose, teacher.

Student 4: The production of paper bags harms forests.

Student 8: Bioplastics are destroyed in a short time in nature, and so do hydrogels. Production processes are easy. Then we can produce a bioplastic or a hydrogel.

Upon this dialogue, one group decided to produce hydrogels and the other group to produce bioplastics. In this section, the process was continued with the solution of the hydrogel-producing group as an example.

The students also determined which plants are commonly used to impart antimicrobial properties to material by determining the importance of antimicrobial properties in their literature research. The teacher guided the students to determine the steps (Afacan & Kahraman, 2021) that they should follow to produce a biodegradable food storage material (polymer) in line with their research.

Teacher: According to your literature readings, what are the examples of plants in our country that show antibacterial properties?

Student 3: Lavender, mint, cloves, etc. There are many plants.

Teacher: Now, let's produce biodegradable food preservation material using these plants. Let's review the process in the literature once again. What materials did they use other than plants?

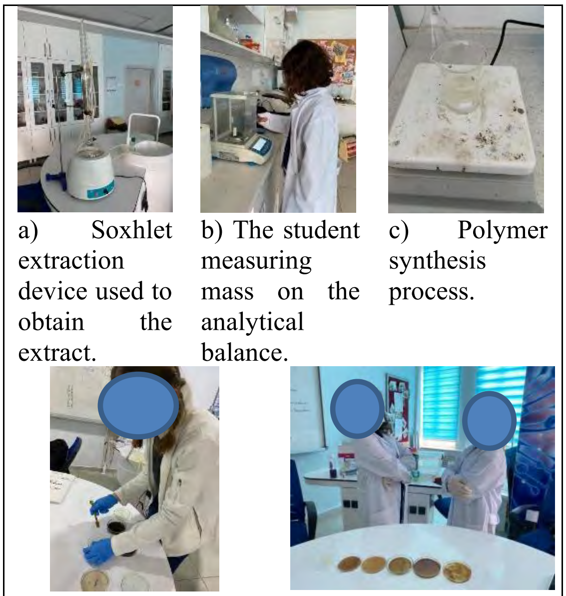
Several Students: Sodium alginate, calcium chloride for hydrogel.

Teacher: Now, let's prepare these materials and carry out our production.

The students followed the following process for hydrogel production under the teacher's guidance (30 min.): They put 1 g sodium alginate and 50 mL pure water in a beaker to synthesize the hydrogels. Then, they stirred the beaker for 1 hour at 600 rpm in a heated magnetic mixer. After the mixing process, they cooled it down to 25°C. Then they added 195 µL glycerin to the beaker. They kept it in an ultrasonic water bath for 15 minutes. 72 hours after they poured the material into the Petri dishes, they added $CaCl_2$ to cover the entire surface and left it for 5 minutes. After that, they washed it with pure water for 5 minutes and left it to dry under room conditions.

Finding Solutions and Choosing the Most Suitable Solution

Students practiced the hydrogel production process. Then, they were asked to carry out this process with plant extracts with antibacterial properties and wrap this material in chicken and make observations and measurements about the spoilage of food. Students also performed their synthesis using 50 mL of plant extract (extracts obtained from plants with antibacterial properties: plants such as clove, mint, pennyroyal, lavender, etc.) instead of 50 mL of distilled water. They used the Soxhlet extraction device to prepare the plant extract. The images of the studies for this process are given in Figure 1 (180 min.).



a) Soxhlet extraction device used to obtain the extract.

b) The student measuring mass on the analytical balance.

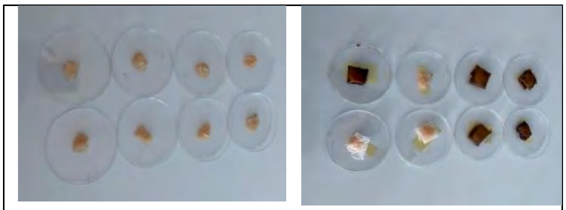
c) Polymer synthesis process.

d) The student pouring hydrogels into Petri dishes.

e) Hydrogels produced by students.

Figure 1. Experimental Processes

The students wrapped equal masses of raw chicken pieces in hydrogels they cut in equal sizes (Figure 2) and stored them under room conditions to determine whether the biodegradable storage materials (hydrogels) affect the shelf life of foods. They noted the day the food started to spoil and their observations about spoilage by observing it for 15 days. They created a table showing the shelf life of foods according to the hydrogel they synthesized (Appendix 5) and presented their data graphically (Figure 3).



a) Equal mass of raw chicken weighed by students.

b) Chicken pieces wrapped in hydrogels.

Figure 2. Biodegradable Storage of Chicken

Concepts that emerged in the process that students used when performing biodegradable polymer synthesis were discussed with the students. They decided to use the hydrogel produced from clove extract, which gave the best results by interpreting the observation notes, tables and graphics they created about the hydrogels they produced, in the production of biodegradable packaging (60 min.).

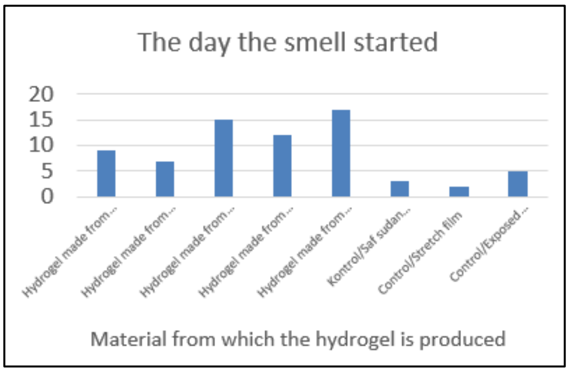


Figure 3. Experimental Findings

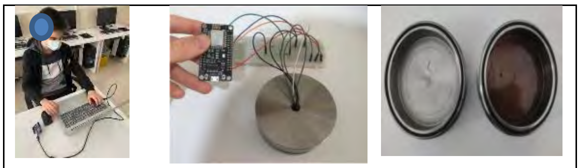
Then, the smart packaging design process started with physical computing. First of all, the teacher asked, "Can the packaging show the microbial spoilage, oxidative changes, and temperature-related changes in the products? Can smart packaging be designed to show such changes?" He discussed these questions with the students. The following questions helped students think about their design and identify the features of smart packaging:

- What features should smart packaging have?
- What information should smart packaging receive from the environment where the food is located and what warnings should it give based on this information?

After the students decided on the characteristics of the packaging (Smart packaging should contain features that will provide information about the temperature of the environment and the amount of gas in the environment during the storage and transportation processes of the food), they were asked to write the operation process of the smart packaging system step by step in verbal expressions and create its algorithm (Appendix 6). In this process, the students decided to design a smart packaging that measures the temperature and gas values in the environment where the food is present and gives information about the spoilage of food, using the biodegradable polymer they produced. During the decision phase, some students suggested using a pH sensor to measure the pH of the environment. However, they decided that it would be difficult to take measurements due to the different pH values at which different bacteria can live. Some students suggested using a humidity sensor. They also gave up using a humidity sensor because the moisture contained in the food used would affect the humidity in the environment. They decided to use temperature and gas sensors, considering that there would be no disadvantages they would encounter in pH and humidity for temperature and gas values (40 min.). In the large group discussion, both groups decided to use temperature and gas sensors. The algorithm creation process was also carried out with the cooperation of two groups. However, one of the groups carried out the process by using bioplastic as the material, and the other group used the hydrogels they produced.

Prototyping, Testing, and Development

The students made the prototype for the biodegradable smart packaging design by using the hydrogel they synthesized from the clove extract, which they determined to be able to store the chicken for the longest time. In this process, they physically set up the electronic circuit with Arduino tools and coded it according to the algorithm they determined (80 min.) (Figure 4 and Appendix 7). Using the system they designed, the students took temperature and gas measurements of the environment where the food in the system was located three times a day for a week. They showed the measurements they obtained in tables and graphs [see Appendix 8, Figures 5 and 6). In the process, the physical components of the smart system and the deficiencies in coding were eliminated and they worked for improvement (80 min.).



a) Student coding for smart packaging.	b) The system created by the students to give information about the spoilage of food.	c) The system created by the students to give information about the spoilage of food.

Figure 4. Students' Work with Arduino

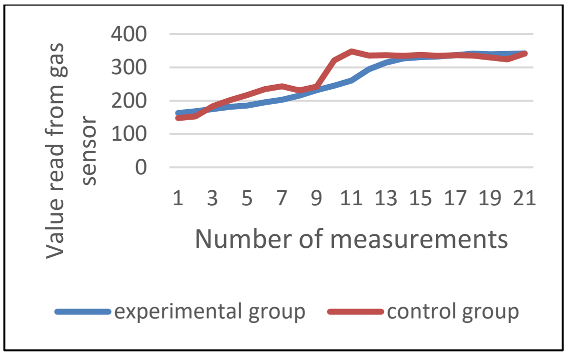


Figure 5. Measurements from the Gas Sensor

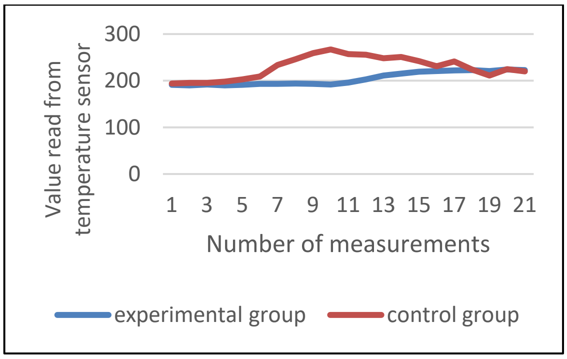


Figure 6. Measurements from the Temperature Sensor

Sharing and Evaluation

The students wrote a report about their findings. The teacher guided them for the report to include topics such as method, findings, results, and bibliography, starting from the problem situation (Appendix 9). After the students prepared their report, they turned it into a digital presentation and shared it with the class (100 min.). After the presentations, the teacher and students conducted process and product evaluations by using the rating scale prepared in Kahoot (20 min.) (Appendix 10). Open-ended questions were used to evaluate the objectives. Finally, the teacher asked, "Which engineering careers do you think the activity tasks are relevant to?". The students' responses included fields such as chemical engineering and software engineering. In addition, the students presented the products they obtained as a result of their studies on various platforms (Appendix 11).

RESULTS and SUGGESTIONS

An evaluation was made in line with the notes taken by the teacher based on his observations during the activity implementation process. It is considered that the current STEM activity enabled the students to reach some cognitive gains, as well as contribute to the development of engineering skills, scientific process skills, and 21st-century skills. The students learned the causes of food spoilage, what can be done to prevent spoilage, the importance of freshness and naturalness of foods for a healthy life, the harm caused by plastics to nature, the consequences of global climate change caused by plastics, and polymerization reactions through their research and activities in the field of science. The students, who knew the features of smart systems in the technology field, chose the appropriate sensors for the smart system they would design with physical computing and developed the smart system with coding. They designed smart packaging using the engineering design process. They carried out activities such as creating algorithms, collecting data in packaging, and displaying the numerical data they collected in tables and graphs. According to the teacher's filed notes, in the activity, the students stated that when they first encountered the problem, they were intertwined with plastics in their daily lives and that they were aware of the increasing use of plastics day by day. Since gifted students are eager to read about environmental issues and talk to their parents about them (Treagust et al., 2016), the problem has attracted their attention. They wanted to share their thoughts on plastics and the harm of it to the environment, and one of the students shared a video he watched about the seventh continent with his friends. This process motivated the students to do something about it, and they were very willing to solve the problem. They immediately wanted to do a literature review on the solution. As they became more knowledgeable about the biodegradable polymers that they could produce under laboratory conditions, their desire to work on the subject increased even more. However, they had to repeat the polymer synthesis when they had difficulties in producing polymers of the desired thickness and size during the polymer synthesis process. After a few tries, they were able to produce polymers of the desired size and thickness. While making the system smart, students with less coding knowledge had some difficulties. However, students with coding knowledge carried out peer learning by supporting their friends. In the process, the teacher guided the students to reach the right resources and motivated them to complete the activity. When the students successfully synthesized the polymer and started to receive the first data from the smart system they developed, they were very happy and proud of the product. Presenting their products on national and international platforms excited them. After this study, they suggested organizing an event to raise awareness of the global climate change caused by plastics and asked their teachers for help.

Students had the experience of using many skills such as engineering skills, scientific process skills, and CT in a collaborative way during the activity. It is stated that such experiences are very effective in the development of skills (Sarı et al., 2020; Strong, 2013). It is important to integrate the engineering design process into the education of gifted students (Katehi et al., 2009). The students were encouraged to identify and solve the problem in this activity, and an effective engineering integration was ensured by creating a creative learning environment (Basham & Marino, 2013). The students tried to solve the real-life problem just like an engineer. During the process of product development aimed at solving the problem, the students used engineering skills such as analyzing the problem, generating ideas for the solution, planning, prototyping, testing, design execution, quality control, reporting, teamwork, analyzing instructions, modeling and making a math-computer connection by using the knowledge of the engineering field and branches. It can be said that this process can positively affect students' self-efficacy and their attitudes and motivations toward STEM fields and careers (Ayverdi & Öz Aydın, 2022; Ihrig et al., 2018). The students used basic and combined scientific process skills (Şen & Nakiboğlu, 2014) in the inquiry process of the activity. Observing, measuring, classifying, data recording, and communication skills, which are among the basic science process skills, were the skills most used by the students. Since the students also planned the experimental design, and the teacher acted as a guide in this process, they also actively used the combined process skills. Among the combined process skills, scientific process skills such as forming hypotheses, constructing experiments, determining, changing, and controlling variables, using data and creating a model, making decisions, and inferring are the skills actively used by the students in the experimental process. Many studies have emphasized that STEM activities are effective in the development of scientific process skills (Ayverdi & Özaydın, 2022; Barış & Ecevit, 2019; Robinson et al., 2014).

The intelligent packaging design was carried out in the activity through physical computing. The students first defined the problem and divided them into sub-problems in this process. Then, they created an algorithm with verbal expressions by listing the necessary steps for the solution. They created the prototype with physical components and coded it according to the algorithm. The operation of the system was tested and any errors in the coding were corrected. After that, data was collected from the package by the gas and temperature sensor. This process was continued automatically within the time specified in the coding. Data editing was done by turning the collected data into tables and graphs. These stages used by students in the physical computing process are the sub-dimensions of the CT process (problem identification, decomposition, algorithm creation, automation, data editing, and modeling) (Kalelioglu et al., 2016; Sarı & Karaşahin, 2020). In other words, the students carried out intelligent packaging design in the CT process through physical computing. This process is also thought to be a good example of the integration of technology into STEM activities. On the other hand, the students used their problem-solving skills while solving real-life problems, their creativity while putting forward different ideas for the solution of the problem, algorithmic thinking while designing algorithms, collaborative thinking with teamwork, and communication skills while presenting their designs in a learning environment and on different platforms. Therefore, it can be said that they use CT, which is considered a common reflection of these skills (Korkmaz et al., 2017).

The point that makes this activity different is that differentiation, which is an important concept in the education of the gifted, is prioritized in the activity setup. Considering the principle of complexity in content differentiation, it was ensured that different features such as reducing greenhouse gas emissions, being biodegradable, storing food safely for a long time, and giving information about the spoilage of food were brought together in the solution of the problem. Thus, attention was paid to the fact that the real-life problem given to the students was a complex, deep, and real problem (Little, 2012; Renzulli & Renzulli, 2010). Method knowledge was used to synthesize biodegradable polymers and measure the spoilage status of foods in the activity. According to Alevli and Okur (2021), students' use of their method knowledge in the problem-solving process enables the adoption of an interdisciplinary approach toward solutions under the diversity principle. Physical computing was used to develop CT skills as process differentiation in the activity. Thus, appropriate methods and techniques were used to develop high-level thinking skills (Heacox, 2002). According to Dinnocenti (1998), in product differentiation, attention is paid to the fact that the problem given to the students is a real-life problem and that the product meets the needs of the real target audience. The need for a smart system in food storage was discussed in this activity. It is thought to meet the needs of the target audience with the smart packaging design realized through physical computing. Attention was paid to giving the general lines of the product and leaving the solution to the creativity of the students, to provide creativity and diversity in the product. B Biodegradable polymer type (bioplastic, hydrogel, etc.), product properties (temperature, pH, humidity, gas, etc.), and tools to measure these properties (control cards and sensors) are used to provide creativity and diversity in the product.

In the activity, the students were encouraged to engage in inquiry. Also, the students benefited from technology in solving the problem. The activity was carried out in a student-centered and non-judgmental learning environment. Thus, an environment was created that allows students to question, contains different materials, and combines school experience with the real-world (Berger, 1991).

This study presents a STEM activity in which physical computing is preferred in the differentiation process for gifted students. A real-life problem in the students' environment was structured as product, content, environment, and process differentiation by physical computing, and a STEM activity was conducted for gifted students. Students have experienced using engineering skills, scientific process skills, and CT skills during the activity. The activity is interesting, instructive, and motivating for STEM fields, where gifted students can use their potential at the highest level. The study serves as a guide for teachers on how to integrate engineering and technology with STEM disciplines when an appropriate real-life context is created. As a result, it can be said that a qualified STEM education that can reach its goals can be achieved by using real-life problems appropriate to the focus of attention of students, engineering design, and physical computing processes together. In this context, the study will set an example for the teachers of gifted students and guide them.

It is suggested that physical programming can be used to integrate pedagogies such as robotics and coding into STEM activities. The parts related to the differentiation in the activity were carried out to ensure that this activity could be used for gifted students. The activity can be simplified in line with the relevant learning objectives and can be used for students at a normal ability level. This study was carried out with groups of gifted students in the 7th, 8th, and 9th grades. The problem can also be simplified and adapted for younger age groups, or it can be made more complex for older students.

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Appendix 1

Activity Learning Objectives

Next Generation Science Standards Performance Expectation	Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem (3-5-ETS1-2). Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants (HS-ETS1-1). Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering (HS-ETS1-2).
CCSS Standard	Draw on information from multiple print or digital sources, demonstrating the ability to locate an answer to a question quickly or to solve a problem efficiently (RI.5.1). Reason abstractly and quantitatively (MP.2). Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) to address a question or solve a problem (RST.11-12.7). Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible (RST.11-12.9).
Science	Investigates the causes of food spoilage. Explores what can be done to prevent food from spoiling. Searches the damage of plastics to nature. Produces solutions for the part of global climate change caused by plastics with the knowledge of climate change. Synthesizes polymeric products (food packaging) using natural materials. Develops and tests a product to solve real-life problems using polymerization reactions.
Technology	Knows the features of smart systems. Designs an original smart system activity that works with sensors such as temperature, humidity, pH etc. Explains the functions of sensors to be used in smart system design. Decides on the appropriate technique for creating the design.
Engineering	Knows the working areas of chemical engineer and software engineer. Uses the engineering design process.
Mathematics	Collects data on research questions. Shows research data in tables and graphs.

Appendix 2

Student Worksheet (For Experimental Section)

Group Name:
Activity Name:
Program:

Dear students,
You are expected to fill in the worksheet below regarding the experiment in which you wrap the food in the biodegradable materials you produce and observe. It is essential that you fill in the table in the results section and create a graph, especially by converting the findings you have obtained during your observations into tables and graphs.

The name of the experiment:

Purpose of the Experiment:	
Tools and Equipments Used:	
Dependent-independent and control variables in the experiment:	
Experimental Procedure:	
Experiment Result:	

material used in food preservation	Our observations	The day the food starts to spoil
Food not wrapped in any material (control-1)		
Food wrapped in cling film (control-2)		
Food wrapped in biodegradable material produced from pure water (control-3)		
Food wrapped in biodegradable material produced from plant extract		
………………………..		

Graph showing the day on which food spoilage begins

…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………

The results I obtained in line with the observations I made in the experiment and the food storage material I chose:…………………………………………………………..
…………………………………………………………………
…………………………………………………………………

Appendix 3

Engineering Design Process

(TeachEngineering, 2022)

1. Ask: The critical questions that engineers use at the beginning of the production process can also be used by students at the beginning of the process. These questions are: What is the problem to be solved? What do we want to design? For whom? What do we want to achieve? What are the project requirements? What are the limitations? What is our purpose?

2. Research: In this process, students talk to people from many different areas of expertise to determine which of the available products, solutions, or technologies for the problem can be adapted to their needs.

3. Imagine: At this stage, students generate lots of ideas for solutions. By brainstorming, they develop as many solutions as possible. Teamwork is important. Unconventional ideas should be encouraged and not judged. New ideas can be built on the ideas of others. Students should be focused on the subject.

4. Plan: In this phase, students review their needs, constraints, and research in the previous steps, select a solution from their best idea, and plan to move forward with that solution.

5. Create: At this stage, students create a prototype. When creating the first version of the prototype, they consider whether the design meets the objectives. They should be encouraged to strive for creativity, imagination and excellence in design.

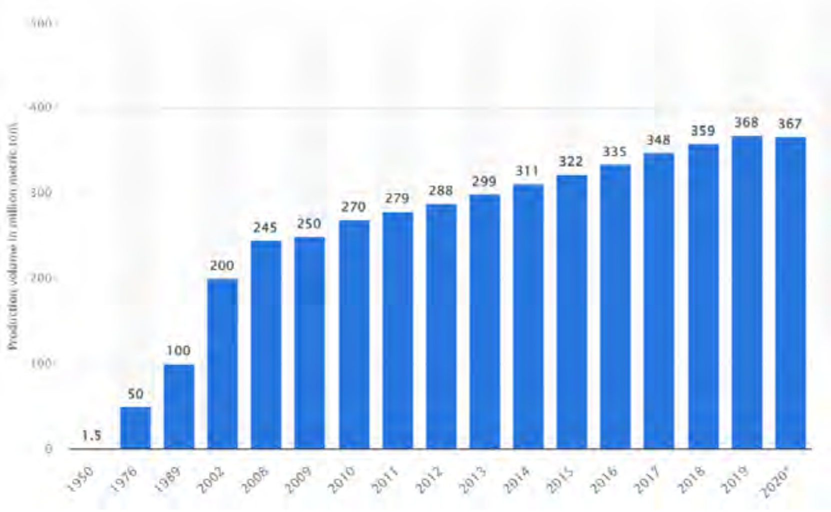
6. Test: At this stage, students analyze whether the prototype contributes to the solution, whether it works, whether it meets the need, what works, what does not work, and what needs improvement.

7. Develop: At this stage, students discuss how they can improve the solution and make revisions. They draw new designs. They strive to make their products the best.

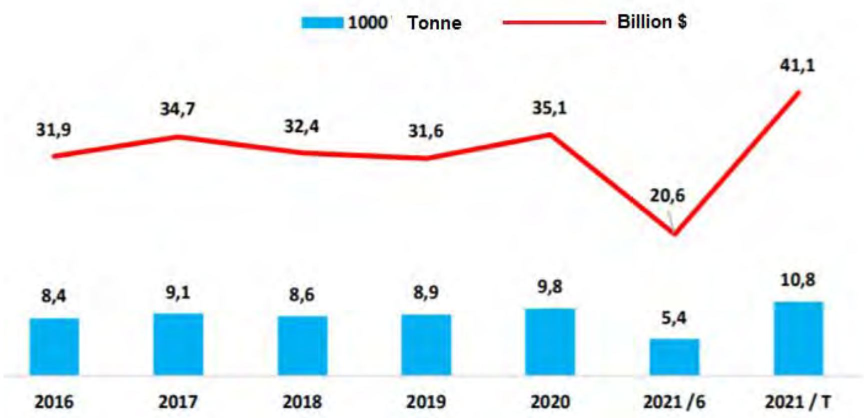
Appendix 4

Plastic Production, Use and Its Impact on Climate Change

Plastics production accounts for the largest part of the chemical industry, accounting for about one-third of chemical production worldwide and about one-fifth in Europe (European Environment Agency, 2022). The production and use of plastic are increasing day by day around the world. Graph 1 contains information on worldwide plastic production from 1950 to 2020 (Statista, 2021). While plastic production in the world has increased over the years, plastic production in Turkiye is also increasing rapidly. Graph 2 shows plastic production in our country in the last five years (Turkish Plastics Industrialists Research, Development and Education Foundation [PAGEV], 2021). Plastic production and consumption processes require the use of fossil fuels that affect global climate change. If plastic production and usage increase as predicted, the plastics industry is expected to account for 20% of global oil use by 2050. Annual emissions due to plastic production in the EU correspond to 13,400,000 tons of CO2, while this rate corresponds to about 20% of the emissions in the chemical industry across the EU (European Environment Agency, 2022). One of the areas where plastics are used the most is the packaging industry (PAGEV, 2021).



Graph 1. World plastic production from 1950 to 2020 (million metric tons) (Statista, 2021)



Graph 2. Plastic production in Turkey from 2016 to 2021 (PAGEV, 2021)

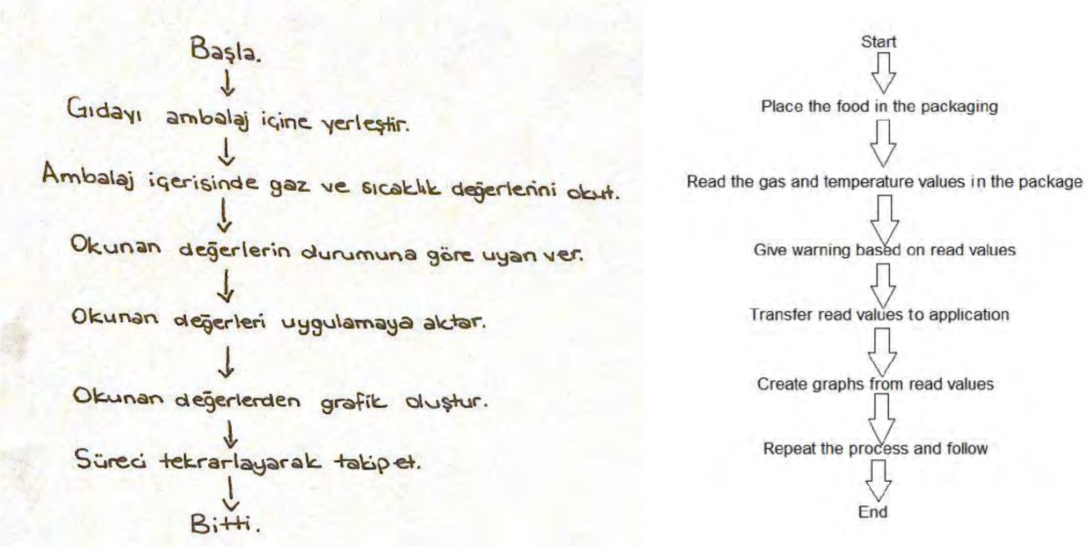
Appendix 5

Observation Table Created by the Students about the Final State of the Chickens Wrapped in the Produced Hydrogels

Chicken wrapping material	Current status of chickens	Observation
Hydrogel produced from pennyroyal *(Mentha pulegium L.)*		The chicken also changed color because of the color of the hydrogel. There was some hardening. However, it gave off less smell than chicken wrapped in stretch film, left exposed, produced without extracts and wrapped in hydrogels made from thyme. It started to give off smell on the ninth day.
Hydrogel produced from ball thyme (*Origanum onites L.*)		The chicken also changed color because of the color of the hydrogel. There was hardening. However, it gave off less smell than chicken wrapped in stretch film, left exposed, produced without extracts and wrapped in hydrogels. It started to give off smell on the seventh day.
Hydrogel produced from lavender /blackhead (*Lavandula stoechas subsp. stoechas L.*)		The chicken also changed color because of the color of the hydrogel. There was some hardening. However, it gave off very little smell. After the hydrogel produced from cloves, it gave the best result in terms of smell. It started to give off smell on the 14th day.
Hydrogel produced from mint (*Mentha x piperita L.*)		The chicken also changed color because of the color of the hydrogel. There was some hardening. However, it had very little smell. It gave the third best result in terms of smell, after the hydrogel produced from cloves and lavender. It gave off smell on the 12th day.
Hydrogel produced from clove (*Syzygium aromaticum*) leaf		The chicken also changed color because of the color of the hydrogel. There was some hardening. However, it did not give off smell. It gave the best results in terms of smell.
Control/Hydrogel made from pure water		Since the hydrogel was colorless, the color of the chicken also darkened slightly. There was some hardening. However, it gave off smell a lot. It gave the second worst result in terms of smell after the stretch film. It started to give off smell on the third day.
Control/Stretch film		Since the stretch film was colorless, the chicken did not change color either. There was no hardening. However, it gave off a smell a lot. It gave the worst result in terms of smell. It started to give off a smell on the second day.
Control/Exposed chicken		The exposed chicken darkened a little. There was hardening. However, it gave off smell a lot. It gave the third-worst result for smell, after chicken wrapped in stretch film and in hydrogels made from pure water. It started to give off smell on the fifth day.

Appendix 6

The Algorithm Created by Students Verbally



Appendix 7

Codes Created by the Students

```
#define BLYNK_PRINT Serial
#include <BlynkSimpleEsp8266.h>
#include <ESP8266WiFi.h>
char auth[] = "xOnKvLDZxOAVILyjy1GhUEz1gzFApV-j";
char ssid[] = "TurkTelekom_Z44AY"; // ssid
char pass[] = "f6fC72aC7E38f"; // password
int readD1;
int readD2;
int Pin_D1 = 4;
int Pin_D2 = 5;

void setup() {
    Serial.begin(9600);
    pinMode(Pin_D1, OUTPUT);
    pinMode(Pin_D2, OUTPUT);
    pinMode(A0, INPUT);
    Blynk.begin(auth, ssid, pass);

}
```

```
void loop() {
    Blynk.run();

    digitalWrite(Pin_D1, HIGH);
    delay(100);
    readD1 = analogRead(0);
    digitalWrite(Pin_D1, LOW);
    delay(100);
    digitalWrite(Pin_D2, HIGH);
    delay(100);
    readD2 = analogRead(0);
    delay(100);

    Serial.print("sensor 1 = ");
    Serial.print(readD1);
    Serial.print(" / sensor 2 = ");
    Serial.println(readD2);
Blynk.virtualWrite(V5, readD1);
Blynk.virtualWrite(V6, readD2);
if (readD2 > 300 , readD2 < 600 ) {
    Blynk.notify("Gas level is critical");
  }
if (readD2 >= 600) {
    Blynk.notify("Gas level is high");
  }

if (readD1 > 300 , readD1 < 600 ) {
    Blynk.notify("The temperature level is critical");
  }
if (readD1 >= 600) {
    Blynk.notify("Temperature level is high");
  }


}
```

Appendix 8

Values Taken from MQ-2 (gas) and DHT-11 (temperature) Sensors for the Experimental and Control Groups

Experimental group (covered with clove extract hydrogel)		Control group (left exposed)	
MQ-2	DHT-11	MQ-2	DHT-11
163	191	148	194
168	190	153	195
175	192	184	195
182	190	202	198
186	191	217	203
195	193	235	209
203	193	243	234
215	194	231	246
232	193	242	259
245	192	321	267
261	196	348	257
294	203	336	256
314	211	337	248
327	215	335	251
331	219	338	242
333	221	335	231
337	222	337	241
341	223	336	224
339	221	330	211
340	224	324	225
342	223	341	220

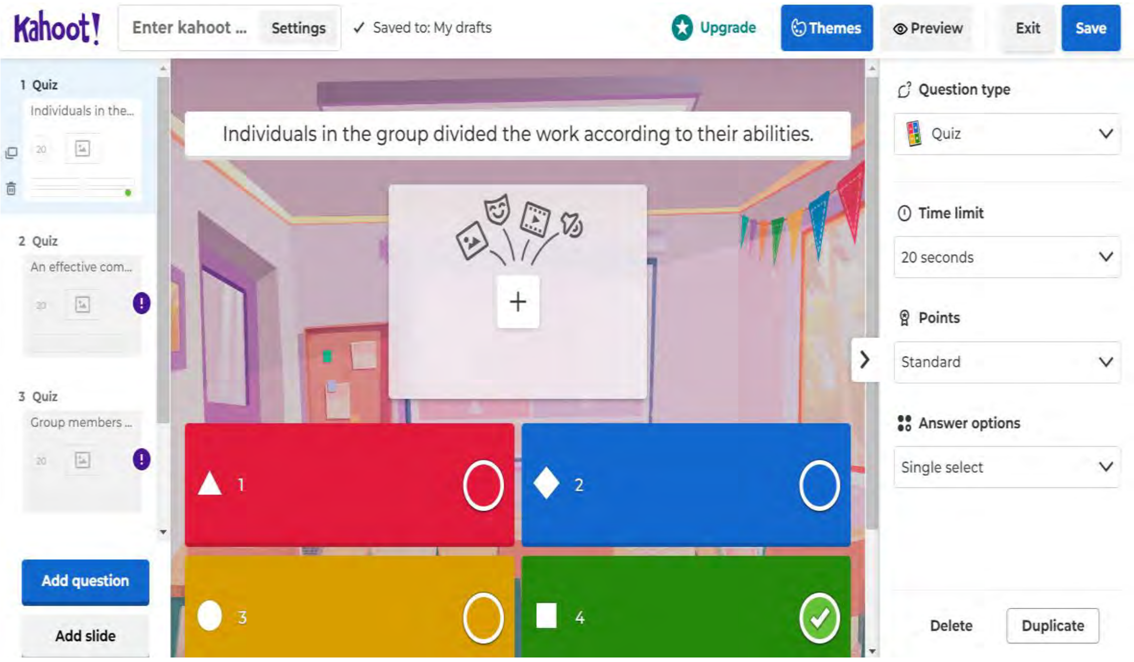
Appendix 9

Report Template Given to Students

Report Template	
Project Title:	
Abstract:	
Key words:	
Aim:	
Introduction (Problem Situation):	
Method:	
Result and Finding:	
Suggestion:	
References:	

Appendix 10

Kahoot Activity



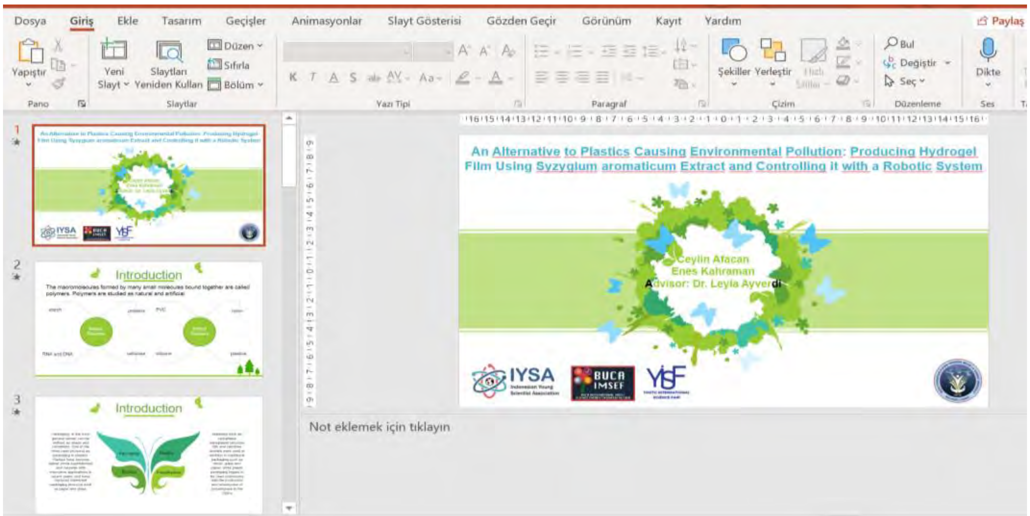
Kahoot (Rating Scale)

Group Name: **Activity Name:** **Program:**				
Instruction: This rating scale has been prepared to evaluate the STEM activity carried out in terms of process and product. With this scale, it is aimed that the groups evaluate themselves and the teacher evaluates the group. Please mark the degree of realization of the criteria you observed on the scale.				
Criteria	**1** **(Inadequate)**	**2** **(Middle)**	**3** **(Good)**	**4** **(Very good)**
Individuals in the group divided the work according to their abilities.				
An effective communication took place within the group.				
Group members effectively presented the product they designed.				
An interdisciplinary perspective was used in solving the problem.				

Students used the engineering design cycle in the design process.				
The product has produced a solution for the problem.				
Limitations have been adequately taken into account in the development of the product.				
The designed product is original.				
The designed product is low cost.				
The designed product is aesthetic.				
The product is useful.				
The designed product is suitable for use in different areas (home, factory, etc.)				

Appendix 11

Students' Additional Presentations



An example of a presentation by students on an international platform

Students presenting on the international platform

A screenshot during the announcement of the results on the international platform