Indonesian Society for Science Educators

Journal of Science Learning

journal homepage: ejournal.upi.edu/index.php/jslearning

9th Grade Students' Learning of Designing an Incubator through Instruction Based on Engineering Design Tasks

Fethiye Karsli Baydere[1]*, Aydın Murat Bodur[1]

[1]Department of Mathematics and Science Education, Faculty of Education, Giresun University, Giresun, Turkey

*Corresponding author: fethiyekarsli28@gmail.com

ABSTRACT In this study, a STEM activity was designed in which 9th-grade students can complete the task of making incubators by overcoming the difficulties they face in the engineering design process. This activity has been handled in the context of energy conversion and prepared based on the engineering design process consisting of 9 stages. The activity was applied to 34 (19 females and 15 males) 9th-grade students studying at a public school in the Eastern Black Sea Region in Turkey in the fall semester of the 2019-2020 academic year. This application took 7 lesson hours (7x40 minutes) in total. At each stage of the engineering design process, students worked like an engineer and scientists by collaboratively conducting scientific research and inquiry. Throughout the process, students were confronted with several difficulties, given the time and opportunity to help them develop STEM literacy. More importantly, the students had the opportunity to experience a STEM activity by putting the steps of the engineering design process into practice.

Keywords STEM Education, Design of an Incubator, Engineering Design Process

1. INTRODUCTION

Science lessons aim to raise individuals who can develop rational and alternative solutions to our problems in real life (Bybee, 2010; 2013; National Research Council [NRC], 2012). It is necessary to use well-planned, responding to today's needs and contemporary teaching methods and techniques in the field of science education in order to raise individuals with this characteristic (Uluçınar, Cansaran, & Karaca, 2004). In other words, it is necessary to create learning environments where memorization is pushed to the background, developing 21st-century skills, where experience is at the forefront, and allowing creative solutions to real-life problems. One of the approaches that create learning environments with these characteristics is the STEM education approach (Akgündüz et al., 2015; Eroğlu & Bektaş, 2016). The educational approach that enables individuals to identify the problem situation, to be able to develop alternative and practical solutions to the problem, and offer creative and original solutions by integrating science, technology, engineering, and mathematics disciplines is called "STEM" (Altunel, 2018; Bybee, 2010, 2011; Yılmaz, Yiğit Koyunkaya, Güler, & Güzey, 2017). While science or mathematics in education is often mentioned in science and mathematics curricula, technology or engineering is rarely referred to, and this is a matter to be solved (Bybee, 2010; Katehi, Pearson, & Feder, 2009). These areas included in the concept of STEM are interrelated and cannot be considered separately (Thomas, 2014). The main reason for the STEM education approach to become widespread is the lack of knowledge in STEM fields and the insufficient workforce (Kennedy & Odell, 2014; Rosenblum & Kazis, 2014). Since the STEM education approach is based on a social constructivist framework, we can characterize science learning as putting social acculturation and personal construction of ideas into practice. STEM disciplines offer a variety of opportunities to gain 21st Century skills. Students studying according to the STEM education approach can develop 21st-century skills such as adaptation, effective communication, social skills, non-routine problem-solving, self-directedness/self-improvement, and systems thinking (NRC, 2012). Some studies on the STEM education approach state that it gives all students a chance to apply their knowledge (Ritz & Fan, 2015; Yıldırım & Altun, 2015). In other words, STEM education and engineering practices offer students the time and opportunity to understand where and how to use

Received: 13 June 2022
Revised: 16 October 2022
Published: 27 November 2022

scientific knowledge. At the same time, it was concluded that the participation of students in activities related to STEM applications increased their interest in STEM fields (Dabney et al., 2012; Maltese & Tai, 2011; Tindall & Hamil, 2004). The STEM approach allows students to blend information. As a result of the blending of the information, it becomes easier for the students to create alternative solutions to the problems they encounter (Morrison, 2006; Niess, 2005; Yıldırım, 2016, 2017; Wang, 2012). This allows students to improve their skills and use them in solving different problems. The STEM approach has made a noticeable difference in the students' interest and motivation toward the lessons (Niess, 2005).

In the STEM education approach, students are first given a problem from daily life. Then, the students think about and investigate the problem situation. Students participate in the inquiry processes of the STEM education approach individually or as a class. Doing research and inquiry enables students to take responsibility for learning and increase their self-confidence (Lewis, 2006). Then they use alternative solution suggestions to solve the problem. Next, they determine the best solution in the context of the problem and make a prototype for the solution. Then, they test whether the prototype solves the problem and improve their design until the prototype is successful. Finally, they share the information they learned and the designs they developed during this process, called the engineering design process, with their peers. All these processes provide students with important experiences. In this context, it is aimed to develop and implement an activity based on the engineering design process in this study. In the activity developed, a real-life problem was presented to the students in which they could use the primary fields of science, technology, mathematics, and engineering. This way, students will have the opportunity to experience an applied activity based on integrating four main disciplines by using their science, technology, mathematics, and engineering skills and by conducting research and inquiry. In this way, they will be productive students.

1.1 Engineering Design Process (EDP)

Turkey's education policies aim to generalize STEM education, train students with engineering skills, and direct students with these characteristics to engineering fields (MEB-YEĞİTEK, 2016; MNE, 2018). The need to introduce engineering design concepts and processes to achieve these goals is recognized. The purpose of introducing EDP to students is not to "build things", which is a common misconception. Instead, EDP aims to teach students that engineering is about organizing thoughts to improve decision-making to develop high-quality solutions and/or products to problems (Bybee, 2010; Dym, Agogino, Eris, Frey, & Leifer, 2005; Gencer, Doğan, Bilen, & Can, 2019). EDP is a process that involves students producing practical solutions to the problem, choosing the most appropriate solution, and designing a product using the solution they choose (NRC, 2010). In this process, students try to find solutions to real-life problems and design and test an original product by applying the EDP steps sequentially. They consider some criteria and limitations to successfully solve the problem (Brunsell, 2012; ITEA, 2007; NRC, 2012). In this process, students will share responsibility by doing collaborative work in groups and developing their creativity while finding solutions to real-life problems.

Experienced engineers work together to systematically explore and evaluate design ideas before investing substantial resources to fully implement them (Daly, Adams, & Bodner, 2012; Wendell, Andrews, & Paugh, 2019; Wells, 2016). In addition, students critical thinking skills will be employed while finding a solution to the problem in this process. In addition, students will use their communication skills to influence others in the engineering design process as part of presenting and disseminating their designs. Similarly, the task of the team of engineers who have designed and successfully prototyped a new product continues beyond there. After that, they need to explain the basic elements that determine how their designs will go into mass-produce to their production engineers (Wendell et al., 2019). In other words, experienced engineers must also have high communication skills. Design tasks assigned to students enable the development of critical thinking skills and are often associated with engineering and technology literacy. STEM experiences significantly impact students' critical thinking development (Duran & Sendag, 2012; Mater et al., 2020). With actual engineering practices, high school students will learn that design is not just about building things. Instead, they will realize it is a process in which the need or problem is clearly defined. Moreover, they will realize that designing is a process that includes research, planning, brainstorming, testing, evaluation, communication, and more.

Engineering design learning experiences are increasingly offered, but research on how to support learners' knowledge construction during the engineering design process in the classroom is still preliminary (Wendell et al., 2019). In this context, the current research is based on the development of a STEM activity according to EDP, its application to students, how to support learners' knowledge construction, and the students gain experience in this process. In addition, this research aims to provide students with STEM experience and present an example to practitioners and teachers on STEM integration.

1.2 Energy Conversion and Design of an Incubator

In science, energy transformation constitutes a privileged and crucial conceptual field due to its abstract and interdisciplinary characteristics. Energy transformation has been significant in science, engineering, and mathematics in the past and current centuries. It will continue to be given. Researchers generally investigated students' alternative concepts and level of understanding within the scope of energy transformation subjects (e.g., Liu & Tang, 2004; Park & Liu, 2016; Töman & Çimer, 2012; Watts, 1983). They also investigated how the effects of different pedagogical approaches on students' understanding of energy transformation differed (Yavuz-Topaloğlu & Balkan-Kıyıcı, 2017; Ozkan & Umdu-Topsakal, 2020). Although these studies have created much information about how students think about energy transformations and which learning approach facilitates students' conceptual understanding of this subject, they did not address whether or how students applied the concepts they learned by selecting appropriate objects and materials for practical tasks. In addition, STEM activity development researches in Turkey are very limited compared to other types (Aydın Günbatar & Tabar, 2019; Ormancı, 2020). In the present study, it was considered necessary that students both learn about energy conversion and gain experience in the application of the subject during the incubator-making process.

2. METHOD

Since this research was planned to design and implement a STEM activity, the engineering design process-based teaching model was used. The STEM activity developed within the scope of the research was applied to a total of 34 (19 girls and 15 boys) 9th-grade students studying at a public school in the Eastern Black Sea Region in the fall semester of the 2019-2020 academic year. Participants ages range from 15 to 16. The study's sample was selected from the students at the school where one of the study's authors was a teacher. This ensures that the research is conducted in a natural learning environment. A combination of both convenience and purposeful sampling procedures was used in the study. All study participants were informed about the research. In addition, all the students participating in the study declared that they participated voluntarily. The students in the study learned that energy is conserved by transforming kinetic and potential energy types in the 8th grade. The students participating in the study have not previously participated in any teaching activity designed according to the EDP of the STEM education approach.

2.1 The Implementation of the STEM Activity

In this study, a STEM activity was developed and implemented using the EDP steps to convert electrical energy. The objectives of the STEM activity have been determined according to acquisitions of secondary school science, mathematics, and technology courses' curriculums in Turkey (MNE, 2018). While developing activities according to the EDP steps of the STEM education approach, the 9th-grade physics textbooks and the studies on the STEM approach in the literature were examined (Aydın & Karslı-Baydere, 2019; Hacıoğlu & Dönmez-Usta, 2020; Wendell & Lee, 2010; Karslı-Baydere, Hacıoğlu, & Kocaman, 2019; Karahan, Bilici, & Ünal, 2015). By presenting real-life problem/design challenges to the students by the researchers, they were made to work like scientists and engineers (Hynes et al., 2011; Wendell & Lee, 2010). There are three basic concepts in the successful implementation of EDP: (i) students are engineers; (ii) teachers need to listen to their students; (iii) classroom environments need to change to enable learning through EDP properly. The goal of learning engineering design is to encourage students to interact with engineering in hands-on activities as a practical application of mathematics and science. Design challenges or real-life problems presented to students must have various features. These include (1) it should facilitate students' learning; (2) the design challenge must be carefully structured and from real life; (3) the problem must be open-ended with many possible solutions; (4) it must have the criteria and limitations that will lead students to the target; and (5) the designed product should be able to be tested and evaluated (Havice, 2009; Moore et al., 2014; Wendell, 2008; Brunsell, 2012; Silk, Schunn, & Cary, 2009). In this context, a design challenge with these features was presented to the students in the study. The activity was presented as a worksheet for students to be guided correctly in the problem-solving process, to write their thoughts easily, to discuss the topic among themselves, and to pass the application process efficiently. The activity prepared was reviewed by two experts: an academic with studies on STEM education and a teacher with more than ten years of experience in the field. The second author made a teaching intervention in the research. The researcher who made the teaching intervention took a postgraduate course about the STEM education approach and is knowledgeable about the application of this approach. Before implementing the activity, during one lesson hour, students were given detailed information about EDP, the different aspects of the process from other lessons, and what they will do. It is crucial to create a social learning environment because EDP includes identifying problems encountered in daily life, developing alternative solutions to them, and making prototypes that create solutions to the problem (Wendell & Lee, 2010). Thirty-four students were divided into six groups, two groups of 5 and 4 groups of 6 people. In the opening lesson, students learn that their engineering design challenge is to create an incubator model with the necessary conditions for developing a fertilized egg. Over the following six lessons, the students, guided by their teacher and worksheet, conduct engineering tests to identify materials to meet these design requirements. To facilitate their efforts throughout the process, useful websites and science workbooks prompt students to reflect on experiments and observations. Students were expected to produce multiple answers within the framework of the assigned task and do the necessary research. Each group was then asked to plan their designs to solve the problem presented to them. The students identified their needs,

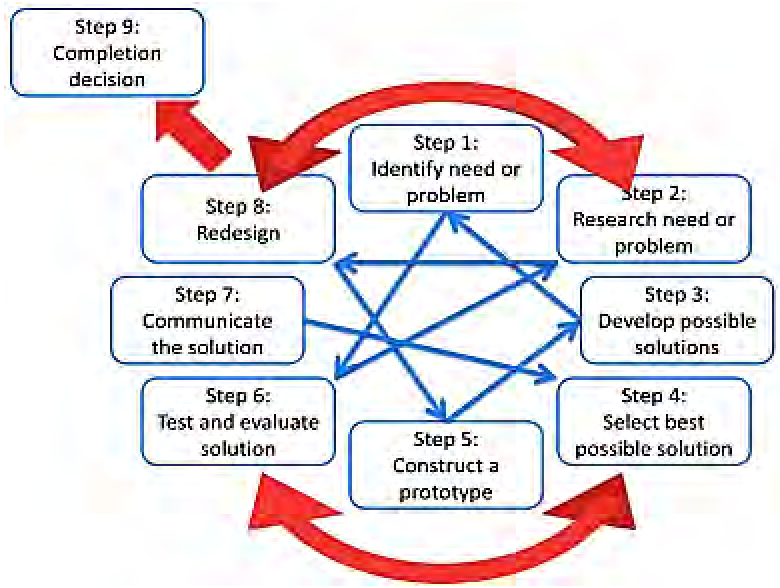


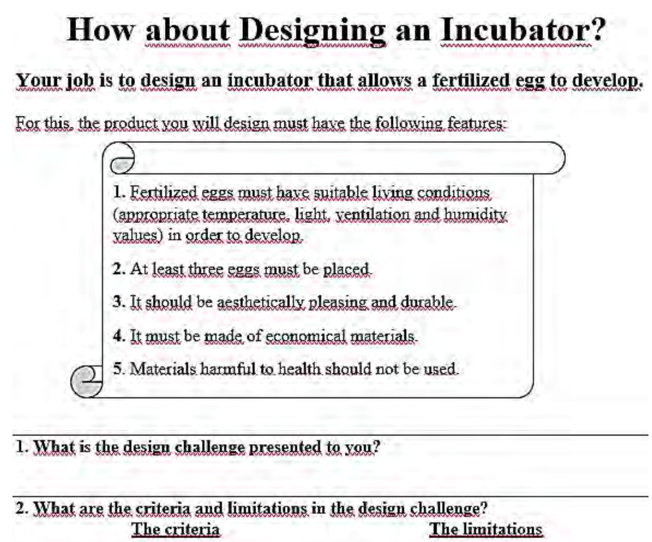
Figure 1 The steps of EDP recommended by Hynes et al. (2011) for 9th-grade students

imagined their planned product, and drew their designs. After providing the necessary materials, they freely designed and tested their products. They used light sensors and temperature sensors for their tests. As the students tested materials and began prototyping, they were asked to make scientific arguments about the materials they would use and their reasons for an incubator. The products designed by all groups were evaluated in terms of criteria and limitations in the classroom. In this study, we focused on students' learning how electrical energy is transformed into other energies through describing, selecting, designing, and testing. Also, we focus on students' conducting scientific argumentation about the solution to the problem through an engineering design component.

In this study, STEM activity was developed according to the 9-step EDP recommended by Hynes et al. (2011) for 9th-grade students on converting electrical energy (See Figure 1). What has been done to all steps of EDP is explained in detail below.

Step 1. Identify and define problems: It is essential to determine the problem at the beginning of the process in EDP. Because when the teacher asks students to find a problem to solve, they will be forced to state the problem in their own words. This approach will increase the likelihood that students will embrace their class challenge and gain critical thinking skills (Hynes et al., 2011; Lemons, Carberry, Swan, Rogers, & Jarvin, 2010). Care was taken that the classroom challenge presented to students is close to a real-world engineering challenge as possible and have open-ended with many possible solutions. In addition, attention was paid to criteria and limitations that guide students to gain knowledge and skills aligned with the targets.

Moreover, care was taken to ensure that the design challenge presented to students could be tested and evaluated in the context of limitations and criteria.


How about Designing an Incubator?

Your job is to design an incubator that allows a fertilized egg to develop.

For this, the product you will design must have the following features:

1. Fertilized eggs must have suitable living conditions (appropriate temperature, light, ventilation and humidity values) in order to develop.
2. At least three eggs must be placed.
3. It should be aesthetically pleasing and durable.
4. It must be made of economical materials.
5. Materials harmful to health should not be used.

1. What is the design challenge presented to you?

2. What are the criteria and limitations in the design challenge?

The criteria	The limitations

Figure 2 The design challenge and directions given to students

Therefore, the application process was first started by leaving the students alone with the design challenge. For this purpose, the design challenge and directions given to students are presented in Figure 2.

Step 2. Research the need or problem: After determining the design challenge and the problem to be solved, there are better ideas for students to try to solve the problem with the first idea that comes to mind. At this stage of EDP, students should be made aware that there are many things they need to consider and know to solve the problem. As students investigate their needs and problem and discover new constraints or ideas, they are more likely to redefine and clarify the problem (Hynes et al., 2011). When dealing with any number of problems embedded in a design challenge, students should decide what information sources o draw upon and what past experiences to apply most effectively (Crismond & Adams, 2012). After ensuring that the students fully understand the problem, the teacher asks them the questions such as "*what do you know to design an incubator?*" and "*what do you need to know?*" It was emphasized that students should collect information from different sources in order to complete their designs successfully. For this, the teacher provides the necessary internet, computer, and library facilities for all students to do their research.

Step 3. Develop a possible solution(s): No single solution to EDP problems is chosen from daily life (Brunsell, 2012; Silk et al., 2009). At this stage, the students were expected to generate many ideas (at least three) by considering the criteria and limitations of the problem given to them. Students wrote their solution suggestions on their worksheets. It was emphasized that they should work in teams and plan for this. During this process, students are expected to brainstorm to use their creativity. This step aimed to help students produce various ideas by asking and guiding questions about the information that students will use while creating ideas. In addition, students exchange ideas with others using their communication skills within the problem criteria and constraints. Students can develop their ideas using words, drawings, and prototypes. Experienced designers participate in continuous learning by brainstorming, drawing, generating ideas, and communicating with people (Lawson & Dorst, 2013).

Step 4. Select the best possible solution: At this stage, the students are expected to choose the best possible solution from the solution proposals they have developed within the given criteria and limitations in overcoming the design challenge given to them (Hynes et al., 2011; NRC, 2012). The teacher emphasized that the students should pay attention to the criteria and limitations of the design challenge while deciding on the best possible solution. At this stage, students think like engineers and evaluate whether their solution proposals meet the criteria and limitations (Brunsell, 2012; Mentzer, 2011; NRC, 2012). For this, the teacher provides the students with instructions: "*Choose the best possible solution among your proposed solutions, taking into account the criteria and limitations of the problem, and present your solution to your other group friends by justifying it.*" Finally, "*Draw the design of the best possible solution you have decided.*" These instructions are also provided to enable students to use their mathematics and science knowledge to make informed decisions and continuously evaluate each (Hynes et al., 2011). The students were then asked to prepare for the next lesson by preparing a plan to implement their chosen solution. In this step, the students planned how to design their solutions and drew what they imagined (See Figure 3).

Step 5. Construct a prototype: A prototype is a model (physical, virtual or mathematical) that represents the final solution (Hynes et al., 2011; Karslı-Baydere et al., 2019; NRC, 2012). The most important feature of this state is that iterative prototyping until an acceptable product is reached, and the students physically create a solution model (Koehler, Latif, Faraclas, Sanchez, & Kazerounian, 2005). It is important to let students fail in making their prototypes and learn from those failures as they replicate their solutions. Even if students fail in the end, they can learn the features of the final solution during the challenge and gain knowledge and skills in many subjects. At this stage, the teacher asked the students to design their products following the solution suggestions put forward by each group. For this, the teacher instructs the students to create their designs. At this stage, the teacher gives all the materials the students will need. During this period, students were encouraged to work just like scientists, engineers, artists, mathematicians, or technologists and began making their designs with their groupmates with the materials they needed.

Figure 3 Group work on selecting the best possible solution

Step 6. Test and evaluate the solution: The usefulness of the presented prototype is vital for a successful solution (Koehler et al., 2005; Karslı-Baydere et al., 2019). Therefore, it is scientifically necessary to test and evaluate the prototype with tests that include criteria and limitations. As a result of this evaluation, the design should be developed until the prototype is successful (Hynes et al., 2011; Brunsell, 2012; Karslı-Baydere et al., 2019).

At this stage, the teacher offers students the opportunity to test their products after they have finished their designs (Figure 4). To do this, it instructs, "*implement your design and test it experimentally. If it does not work, redesign and come to the retesting stage*". Students complete and test their designs.

The designs created at this stage were tested in groups. First, the group discussed why the designs that failed the test did not work. Then, the detected errors and deficiencies were corrected. Finally, the design was rearranged and transformed into a solution to the problem. Thus, all groups had the opportunity to see the success of their prototypes.

Figure 4 3rd group that created their prototypes

Steps 7-8. Communicate the solution and redesign: Implementing engineers share their ideas, solutions, and designs with others for feedback and marketing purposes (Hynes et al., 2011). As engineers do, students can communicate their solutions through presentations, written documents, or other tools. In this process, students must indicate their design presentations' conditions, performances, problems, limitations, and criteria. In doing so, students will make an oral presentation using a language understandable to the target audience.

Figure 5 Group 6 presents their prototype to other groups

At this stage, the teacher asks all groups to present their designs to other groupmates (See Figure 5). At the same time, the teacher asked other groups to comment on the designs presented. Students presented to their group friends how their designs transform electrical energy into heat and light energy. The students explained the reasons for using the materials they used to solve the problem and the difficulties they faced. They documented the extent to which they met the criteria and limitations of the design challenge presented to them. With these practices, students' communication and problem-solving skills were put to work. The students worked in continuous cooperation with their group mates. This situation contributed to the students developing group consciousness. An evaluation rubric was given to the students. The target audience evaluated the designs presented according to various criteria such as offering a solution to the problem, not harming the environment, or economy, suitability for human health, durability, and usefulness. It was decided which one of the designs made by the groups was the best. Thus, the students realized that a good design depends not on a single criterion but on several variables. The teacher instructs the students "*improve your design until a final product that meets all requirements and criteria is produced*." The goal is to ensure that your prototype passes all tests and evaluations.

Step 9. Completion: In this step, students decide that they adequately meet the design requirements and are ready to implement their prototype as a final product (See Figure 6). In this step, after the students have decided that their prototype is ready to implement as a final product, the teacher asks them to introduce their designs by giving instructions, "*prepare a product introduction or user manual to popularize your design*". The aim here is to realize the importance of marketing a developed product and developing a product.

Figure 6 The final design of the 5th group

3. RESULT AND DISCUSSION

In this study, a STEM activity was developed and implemented using the EDP steps to convert electrical energy. EDP is one of the most suitable ways to give students a STEM experience. This experience process also allows students to share responsibility through collaborative work in groups and develop their creativity while trying to find original solutions to real-life problems. Students designing in this process use many learning styles: learning by doing; learning by brainstorming; learning by prototyping; learning from iteration, feedback, and failure; learning by noticing and troubleshooting; learning by drawing and ideas; learning by dialogue with materials; and learning from people and thought (Hathcock, Dickerson, Eckhoff, & Katsioloudis, 2015; Lawson & Dorst, 2013). Students also benefit from different disciplines and improve their skills while solving the problem (Kolodner, 2002a, 2002b; Leonard, 2004).

In this research, ninth-grade students were faced with many difficulties in EDP and were guided to overcome them. As a result, they found solutions to the real-life problem presented by adding their original ideas and employing the disciplines of science, engineering, technology, and mathematics. In addition, they eventually overcame their difficulties and completed the task of making incubators. Educators argue that if students are to improve their STEM literacy, they have to face and solve several difficulties (Bybee, 2010). In this process, the students not only learned how to make an incubator but also learned with fun. They also had the opportunity to develop many aspects, such as harmonious working, effective communication, social skills, new idea development, responsibility, problem-solving, and decision-making.

After the students were challenged to make an incubator, the students began to research, think, and make how the incubator could be made. The researchers observed that not all groups were equally successful in this process. The designs that some groups initially dreamed of and the products they made did not match. In other words, the designs imagined by some groups offered more realistic solutions to the problem, while the products they designed needed help finding a solution to the problem. One of the reasons for this is that they need to correctly combine the tools and equipment necessary to realize their imagined design. In addition, it was observed that some students had problems using their manual skills. At the stage of testing their products, the students could adjust the temperature, light, and humidity values that should be in the environment during the incubation. They tested this by measuring them with appropriate tools. Also, the students followed the process of hatching chicks from a real fertilized egg after the activity was completed. However, no group hatched chicks from fertilized eggs utilizing the products they designed. It is important to let students fail from time to time and learn from these failures as they repeat their solutions (Bybee, 2010) because students can learn while questioning the reasons for failure.

The activity was presented as a worksheet for students to be guided correctly in the problem-solving process, to write their thoughts easily, to discuss the topic among themselves, and to pass the application process efficiently. While this activity is being implemented, it has been observed that the worksheets act as an excellent organizer to guide the students and help the teacher. This shows that worksheets have an important role that students can play in facilitating science learning through authentic activities such as engineering design.

4. CONCLUSION

Considering the whole process, the students needed help creating a solution to the problem and, at the same time, had much fun. In addition, this activity applied to students provided the time and opportunity to help them develop STEM literacy. Therefore, when the whole process is considered, the implementation of the developed activity meets the learning outcomes to a great extent. However, on the other hand, this activity is an example of how science, mathematics, and technology can be integrated into EDP. Based on these results, it is recommended to carry out and disseminate similar studies in different interdisciplinary subjects or concepts that will solve real-life problems.

5. IMPLICATIONS AND FURTHER RESEARCH

Based on these results, it is recommended to carry out and disseminate similar studies in different interdisciplinary subjects or concepts that will solve real-life problems.

In this research, a STEM activity was designed and implemented. Although this is an engineering design development study, the effects of the developed and implemented activity on students could not be examined. However, the effects of the activity developed in further research on various learning products of students can be investigated.

After the activity was completed, the students followed the process of hatching chicks from a real fertilized egg. However, no group hatched chicks from fertilized eggs utilizing the products they designed. When they investigated the reason for this, they found that turning the eggs in the incubator was of great importance during the incubation period. Therefore, the students failed to meet the criteria for rotating the eggs continuously and at an appropriate speed in their designs. This situation could be given as a separate criterion in the problem scenario, or more attention could be paid to this issue with teacher guidance. For this reason, it is recommended that the teachers who will do this activity give more guidance on making a mechanism in the incubator that will perform the proper rotation during the incubation process.

REFERENCES

Akgündüz, D., Aydeniz, M., Çakmakçı, G., Çavaş, B., Çorlu, M. S., Öner, T., & Özdemir, S. (2015). *STEM education Turkey Report*. İstanbul: Scala Basım.

Altunel, M. (2018). STEM Education and Turkey: Opportunities and Risks. *Siyaset, Ekonomi ve Toplum Araştırmaları Vakfı*, *207*, 1-7.

Aydın, E., & Karslı-Baydere, F. (2019). 7th Grade Students' Views about STEM Activities: Example of Separation of Mixtures. *Ondokuz Mayis University Journal of Education Faculty*, *38*(1), 35-52.

Aydın-Günbatar, S., & Tabar, V. (2019). Content analysis of science, technology, engineering and mathematics (STEM) research conducted in Turkey. *YYU Journal of Education Faculty*, *16*(1), 1054-1083.

Brunsell, E. (2012). The engineering design process. In Brunsell, E. (Ed.), *Integrating Engineering + Science in Your Classroom* (pp. 3-5). Arlington, Virginia: National Science Teacher Association [NSTA].

Bybee, R. W. (2010). Advancing STEM education: A 2020 Vision. *Technology and Engineering Teacher*, *70*(1), 30-35.

Bybee, R. W. (2011). Scientific and engineering practices in K-12 classrooms: understanding "a framework for k-12 science education. *Science and Children*, *49*(4), 10-16.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. NSTA press.

Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education*, *101*(4), 738.

Dabney, K. P., Tai, R. H. Almarode, J. T. Miller-Friedmann, J. L. Sonnert, G. Sadler, P. M., & Hazari, Z. (2012). Out-of-school time science activities and their association with career interest in STEM. *International Journal of Science Education*, *Part B*, *2*(1), 63-79.

Daly, S., Adams, R., & Bodner, G. (2012). What does it mean to design? A qualitative investigation of design professionals' experiences. *Journal of Engineering Education*, *101*(2), 187–219.

Duran, M., & Sendag, S. (2012). A preliminary investigation into critical thinking skills of urban high school students: Role of an IT/STEM program. *Creative Education, 3*(2), 241. doi: 10.4236/ ce.2012.32038.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, *94*(1), 104-120.

Eroğlu, S., & Bektaş O. (2016). Ideas of Science Teachers took STEM Education about STEM based Activities. *Journal of Qualitative Research in Education*, *4*(3), 43-67.

Gencer, A. S., Doğan, H., Bilen, K., & Can, B. (2019). Integrated STEM Education Models. *PAU Journal of Education*, *45*(45), 38-55.

Hacıoğlu, Y., & Dönmez Usta, N. (2020). Digital game design-based STEM activity: Biodiversity example. *Science Activities*, *57*(1), 1-15.

Hathcock, S. J., Dickerson, Eckhoff, D. L., & Katsioloudis, P. (2015). Scaffolding for creative product possibilities in a design-based STEM activity. *Research in science education*, *45*(5), 727-748.

Havice, W. (2009). The power and promise of a STEM education: Thriving in a complex technological world. *The overlooked STEM imperatives: Technology and Engineering*, 10-17.

Hynes, M., Portsmore, M., Dare, E., Milto, E., Rogers, C., Hammer, D., & Carberry, A.. (2011). *Infusing engineering design into high school stem courses*. Retrieved from https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1165&context=ncete_publications.

International Technology Education Association (ITEA). (2007). *Standards for technological literacy: Content for the study of technology*. Reston, VA: Author.

Karahan, E., Bilici, S. C., & Ünal, A. (2015). Integration of media design processes in science, technology, engineering, and mathematics (STEM) education. *Eurasian Journal of Educational Research*, *15*(60), 221-240.

Karslı-Baydere, F., Hacıoğlu, Y., & Kocaman, K. (2019). An example of the science, technology, engineering, and mathematics (STEM) education activity: Anticoagulant Drugs. *Kastamonu Education Journal*, *27*(5), 1935.

Katehi, L., Pearson, G., & Feder, M. (2009). *Engineering in K-12 education: Understanding the status and improving the prospectus*. Washington, DC: National Academies Press.

Kennedy, T. J., & Odell, M. R. L. (2014). Engaging students in STEM education. *Science Education International*, *25*(3), 246-258.

Koehler, C., Latif, S. K., Faraclas, E., Sanchez, S., & Kazerounian, K. (2005, June). Engineering Frameworks For A High School Setting: Guidelines For Promoting Technical Literacy For High School Students. In *2005 Annual Conference* (pp. 10-550).

Kolodner, J. L. (2002a). Facilitating the learning of design practices: Lessons learned from an inquiry into science education. *Journal of Industrial Teacher Education*, *39*(3), 9-40.

Kolodner, J. L. (2002b). Learning by design: Iterations of design challenges for better learning of science skills. *Cognitive Studies: Bulletin of the Japanese Cognitive Science Society*, *9*(3), 338-350.

Lawson, B., & Dorst, K. (2013). *Design expertise*. Routledge.

Lemons, G., Carberry, A., Swan, C., Rogers, C., & Jarvin, L. (2010, June). The importance of problem interpretation for engineering students. In *2010 Annual Conference & Exposition* (pp. 15-1238).

Leonard, M. J. (2004). Toward Epistemologically Authentic Engineering Design Activities in the Science Classroom. *Online Submission*.

Lewis, T. (2006). Design and inquiry: Bases for an accommodation between science and technology education in the curriculum? Journal of Research in Science Teaching: *The Official Journal of the National Association for Research in Science Teaching*, *43*(3), 255-281.

Liu, X., & Tang, L. (2004). The progression of students' conceptions of energy: A cross-grade, cross-cultural study. *Canadian Journal of Science, Mathematics & Technology Education*, *4*(1), 43-57.

Maltese, A. V., & Tai, R. H. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among US students. *Science education*, *95*(5), 877-907.

Mater, N. S., Hussein, M, J, H., Salha, S. H., Draidi, F. R., Shaqour, A. Z., Qatanani, N., & Affouneh, S. (2020). The effect of the integration of STEM on critical thinking and technology acceptance model. *Educational Studies*, 1-17. doi.org/10.1080/03055698.2020.1793736.

MEB-YEĞİTEK. (2016). *STEM eğitim raporu* [STEM education report]. Ankara: Yenilik ve Eğitim Teknolojileri Genel Müdürlüğü.

Mentzer, N. (2011). High school engineering and technology education integration through design challenges. *Journal of STEM Teacher Education*, *48*(2), 7.

MNE. (2018). *Secondary School Physics course (9, 10, 11 and 12th grades) curriculum*. Ankara, Turkey: Talim Terbiye Kurulu Başkanlığı.

Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In *Engineering in pre-college settings: Synthesizing research, policy, and practices*. Ed. S¸. Purzer, J. Strobel, M. C. Cardella), pp. 35–60. West Lafayette, India: Purdue University Press.

Morrison, J. (2006). Attributes of STEM education: The student, the school, the classroom. *Teaching Institute for Excellence in STEM*, *20*, 2-7.

National Research Council [NRC]. (2010). *Exploring the intersection of science education and 21st century skills: A workshop summary*. Washington, DC: National Academies Press.

National Research Council [NRC]. (2012). *A framework for k-12 science education: practices, crosscutting concepts, and core ideas*. Washington DC: The National Academic Press.

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and teacher education*, *21*(5), 509-523.

Ormanci, Ü. (2020). Thematic content analysis of doctoral theses in STEM education: Turkey Context. *Journal of Turkish Science Education*, *17*(1), 126-146.

Ozkan, G., & Umdu-Topsakal, U. (2020). Investigating the effectiveness of STEAM education on students' conceptual understanding of force and energy topics. *Research in Science & Technological Education*, 1-20, DOI: 10.1080/02635143.2020.1769586.

Park, M., & Liu, X. (2016). Assessing understanding of the energy concept in different science disciplines. *Science Education*, *100*(3), 483-516.

Ritz, J. M., & Fan, S. C. (2015). STEM and technology education: International state-of-the-art. *International Journal of Technology and Design Education*, *25*(4), 429-451.

Rosenblum, I., & Kazis, R. (2014). Middle-Skill STEM State Policy Framework. *Jobs for the Future*. Retrieved from https://files.eric.ed.gov/fulltext/ED556763.pdf.

Silk, E. M., Schunn, C. D., & Cary, M. S. (2009). The impact of an engineering design curriculum on science reasoning in an urban setting. *Journal of Science Education and Technology*, *18*(3), 209-223.

Thomas, T. A. (2014). *Elementary teachers' receptivity to integrated science, technology, engineering, and mathematics (STEM) education in the elementary grades* (Doctoral dissertation). University of Nevada, Reno.

Tindall, T., & Hamil, B. (2004). Gender Disparity in Science Education: The Causes, Consequences, and Solutions. *Education*, *125*(2).

Töman, U., & Çimer, S. O. (2012). An Investigation into The Conception Energy Conversion at Different Educational Levels. *Erzincan University Journal of Education Faculty*, *14*(2), 289-312.

Uluçınar, Ş., Cansaran, A., & Karaca, A. (2004). The Evaluation Of Laboratory Studies In Science. *Türk Eğitim Bilimleri Dergisi*, *2*(4), 465-475.

Wang, H. H. (2012). *A new era of science education: science teachers 'perceptions and classroom practices of science, technology, engineering and mathematics (STEM) integration* (Unpublished Doctoral Thesis). The University of Minnesota.

Watts, D. M. (1983). Some alternative views of energy. *Physics Education*, *21*, 154-156.

Wells, J. G. (2016). Efficacy of the Technological/Engineering Design Approach: Imposed Cognitive Demands within Design-Based Biotechnology Instruction. *Journal of Technology Education*, *27*(2), 4-20.

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

Wendell, K. B., & Lee, H. S. (2010). Elementary students learning of materials science practices through instruction based on engineering design tasks. *Journal of Science Education and Technology*, *19*(6), 580-601.

Wendell, K. B., Andrews, C. J., & Paugh, P. (2019). Supporting knowledge construction in elementary engineering design. *Science Education*, *103*(4), 952-978.

Yavuz Topaloğlu, M., & Balkan Kiyici, F. (2017). The Effect of Hydroelectric Power Plants Trip on Students' Conceptual Understandings. *Mersin University Journal of the Faculty of Education*, *13*(3).

Yıldırım, B. (2016). *7. Sınıf fen bilimleri dersine entegre edilmiş fen teknoloji mühendislik matematik (STEM) uygulamaları ve tam öğrenmenin etkilerinin incelenmesi* [Examining the effects of science technology engineering mathematics (STEM) applications and mastery learning integrated into 7th grade science course] (Unpublished PhD Thesis). Gazi Üniversitesi, Eğitim Bilimleri Enstitüsü, Ankara.

Yıldırım, B., & Altun, F. (2015). Investigating the Effect of STEM Education and Engineering Applications on Science Laboratory Lectures. *El-Cezeri Journal of Science and Engineering*, *2*(2), 28-40.

Yıldırım, P. (2017). A Qualitative Study On Integration Of Science, Technology, Engineering, And Mathematics (STEM). *Atatürk University Kazım Karabekir Education Faculty Journal*, *35*, 31-55.

Yilmaz, H., Koyunkaya, M. Y., Güler, F., & Güzey, S. (2017). Turkish adaptation of the attitudes toward science, technology, engineering, and mathematics (STEM) education scale. *Kastamonu Education Journal*, *25*(5), 1787-1800.