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A CASE STUDY OF IMPLEMENTING ENGINEERING DESIGN PROCESS TO BUILD A "CONTROLLABLE SWITCH INSTRUMENT"

Nilüfer OKUR AKÇAY, Ezgi AKKUŞ ÇİTFÇİ

Abstract: STEM education serves to prepare a workforce in which integration of scientific information as well as technological literacy are becoming more and more widespread. Important skills for success in the twenty-first century include critical thinking, problem solving, creativity, cooperation, self-directed learning, scientific-environmental and technological literacy. In this study, primary school teacher candidates used a STEM activity, following the engineering design process. The case study, a qualitative research approach, was used in this study. The participants in the study were thirty primary school teacher candidates from second class at university. This study used audio and video recordings and engineering design notebooks as data collection tools. The engineering design process as a context for developing science, mathematics and technology concepts was used. An electrical engineering activity requiring students to design and build an electrical instrument to control the current intensity was created. This activity has been determined in an engineering context where students were introduced to the work of electrical engineers, such as designing basic electric circuits and using different electrical tools. As a result of this research, primary school teacher candidates had an opportunity to experience engineering design-based science education focused on electricity saving, which is a problem they may encounter in real life and also results demonstrated that the adjustable wrench designed by primary school teacher candidates changes the bulb's brightness.

Key words: Engineering design, STEM, primary school, teacher candidates, case study.

1. Introduction

Over the past decade, education in STEM subjects – Science, Technology, Engineering and Mathematics – has received growing attention. Countries have introduced reforms in education to support their economic development. As a result of efforts to change education, STEM became a main focus primarily in the USA, rapidly attracting the attention of European countries and Asian countries such as Korea, Japan, China and Taiwan (Blackley and Howell, 2015). The purpose of STEM education is to provide students with the appropriate skills both to teach and learn STEM disciplines in the earliest grades (National Research Council (NRC), 2012). STEM education is an interdisciplinary approach that combines traditionally presented science, technology, engineering and mathematics, providing students with learning experiences to adapt these disciplines to their lives (Vasquez, Comer & Sneider, 2013). STEM education promotes multi-dimensional learning by integrating different disciplines (Smith and Karr-Kidwell, 2000). In addition, STEM represents the rethinking of traditional approaches in teaching (Fioriello, 2010). STEM subjects can offer students the opportunity to develop problem-solving skills and critical-thinking skills. According to the NRC (2012), learning about science and engineering involves integrating scientific understanding (i.e., content knowledge) as well as practices of engaging in scientific inquiry and engineering design. STEM disciplines therefore offer students an opportunity to experience real-world learning in a multidisciplinary context. Furthermore, STEM education makes learning more meaningful, connected and relevant to students (Stohlmann,

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Moore, & Roehrig, 2012). Beane (1995) stated that a complex and challenging process will increase students’ conceptual understanding of knowledge across several different disciplines by encouraging the integration of disciplines. Engineering design process is important in meeting these disciplines on a single roof. By designing science, technology and mathematics together, students should be provided with STEM education. Furthermore, Moore and colleagues (2014) indicated that design processes are at the centre of engineering practice. When applied effectively, engineering design-based science teaching improved students' problem solving skills (Stinson et al., 2009) and increased academic achievement in science and mathematics (Furner and Kumar 2007; Rehmat, 2015; Wendell, Wright & Paugh, 2017) as well as promoted positive attitudes about STEM (Guzey et al., 2016). Eventually, STEM activities provide students with opportunities to learn science, mathematics, technology phenomena and methods related to embedded practices, such as designing a controllable switch instrument.

We were interested in researching how primary school teacher candidates implemented science, mathematics and technology concepts when given an electrical engineering problem to solve using Engineering Design Process (EDP). The primary school teacher candidates were in the second grade. An important aspect of learning to teach EDP is the discrete type of information that teachers should acquire, especially conceptual knowledge of the EDP. Primary school teacher candidates should know what the EDP includes and how engineers describe EDP. Thus, we adopted the EDP from Moore and colleagues’ framework (2013) and used it to structure the activity. Drawing on students’ learning across their STEM studies, the “controllable switch instrument” activity involved electricity, basic electric circuit, different resistant, we designed the activity to enable application of concepts from all three disciplines. When candidates experimenting with materials to identify their properties they explored the roles of engineers also. To this end, we investigated the following research questions:

1. What are primary school teacher candidates’ views on what engineering is?
2. Can the candidates explain the problem situation for the given scenario?
3. Is there any difference between the candidates’ pre-knowledge and final knowledge about a simple electrical circuit after the experiment?
4. Are there any differences between the candidates’ individual design and group design ideas?

1.1. STEM Education

Shaughnessy (2013) defined STEM education as “solving problems using concepts and procedures from mathematics and science while incorporating engineering and design methodology and using appropriate technology”. As stated in the national reform documents and standards, engineering is the discipline that dominates discussions about STEM education (NGSS Lead States, 2013; NRC, 2012). STEM education serves to prepare a workforce in which integration of scientific information as well as technological literacy are becoming more and more widespread. Important skills for success in the twenty-first century include critical thinking, problem-solving, creativity, cooperation, self-directed learning, scientific-environmental and technological literacy (Howard-Brown & Martinez, 2012). Additionally, STEM education is carried out in a collaborative manner (National Academy of Engineering (NAE & NRC, 2009). Innovation and productivity, which are considered to be keys to increasing living standards, are important skills in STEM fields (Council of Canadian Academies, 2015). It emphasizes a multidisciplinary approach to highlight STEM (NRC, 2014). It was identified as an effective approach to address students' thoughts about integration concerns of the progress (including how students practiced their learning and learned during problem solving) in a STEM problem activity (Capobianco et al. 2018). Integrated STEM education is a student-centred approach that develops students’ problem solving and higher-order thinking skills (Stohlmann, Moore & Roehrig, 2012). Furthermore, it fosters the development of skills such as critical thinking, creativity and innovation in addition to promoting conceptual learning with meaningful real-world practices and creating interest and enthusiasm for careers in STEM fields (Akarsu, Okur-Akçay& Elmas, 2020). This type of learning is very important because students are often unable to make connections between disciplines in integrated STEM activities (Moore et al. 2014). According to the NRC (2009), *science* examines the natural world related with physics, biology, chemistry and their relationship with each other as well as concepts and principles associated with these disciplines. Even though *technology* is not a discipline in the strictest sense, technology encompasses the entire system of people, organizations, knowledge, processes and devices as well as processes for creating and operating technological devices. *Engineering* involves designing man-made products and solving problems, taking into considerations a host of limitations (time, money, existing materials, ergonomics, environmental regulations, manufacturability and repairability). *Mathematics* as used in science, engineering, and technology also examines the patterns and relationships between quantities, numbers and spaces. The basis of the STEM integration approach is to enable students to develop skills in conducting research to solve an engineering problem. Our approach reflects the argument of Moore et al. (2014) that if an engineering STEM integration approach is taken, it can provide real-world context for STEM learning.

1.2. Challenges with STEM integration

It has been determined that there are difficulties in the literature on bringing together the four disciplines in STEM. Some researchers have found that students’ awareness of learning STEM disciplines and how they apply them in an integrated STEM activity remains a challenge for educators (Brophy et al. 2008; Bryan et al. 2015; Bybee, 2010; Cunningham & Carlsen, 2014; Guzey et al. 2019; Moore et al. 2014; NAE & NRC, 2009; Okur-Akçay, 2022; Peterman, Daugherty, Custer & Ross, 2017; Wang, Moore, Roehrig, & Park, 2011). These challenges are presented below:

1. There is a need for well-designed activities that allow students to demonstrate STEM connections.
2. The proliferation of existing STEM models coupled with a lack of practical advice creates general confusion about integrated STEM, which requires training especially for teachers tasked with implementing integrated STEM in classrooms.
3. There is a lack of curriculum materials, a need for assessments in integrated STEM as well as a need for engaging experiences for students.
4. If engineering-based projects do not reinforce students' science practices, these projects can easily become just arts or crafts projects.
5. To implement integrated STEM activities effectively, primary teachers often do not have the necessary pedagogical knowledge.
6. In developing skills in teaching STEM subjects, it has been difficult to find or develop programs that teach all aspects of the curriculum to support teachers.
7. Integrated STEM education requires teachers to show students that STEM concepts are interconnected. These are the areas where students need help because students cannot make these connections on their own.
8. Science teachers are not familiar with engineering, limiting their ability to integrate engineering into science teaching effectively.
9. The teachers need proficiency in STEM pedagogical content knowledge if they want to teach STEM effectively.

1.3. Engineering Design Process

Engineering, which in the broadest sense helps to create solutions for problems, is expressed today as a profession based on academic disciplines including mathematics and science. Engineering design, the problem-solving approach in engineering, is a process that starts with the definition of the problem and ends with the solution that meets the restrictions and criteria defined for the desired performance (International Technology Education Association (ITEA), 2000; NAE & NRC, 2009; NRC, 2012). The engineering design process (EDP) is an ideal platform to integrate science, technology and mathematics and can be used to develop a solution to address a human need (Mangold & Robinson, 2013). With engineering design, students can learn that there are multiple ideas and approaches to solving problems, and multiple solutions, tools and presentations can be used in a variety of ways to produce a desired end product; furthermore, it is acceptable for initial designs to fail (ITEA, 2000). Engineering design as a way of combining STEM disciplines in education has attracted the attention of the international community (The National Academies, 2014). The main role of teachers and teaching materials in this process is to invite and support students to participate in increasingly complex opportunities to perform engineering design, and, while doing so, support students as they design solutions that meet the criteria within the constraints (Wendell, Andrews & Paugh, 2019). Engineering design is a central practice for students engaging in engineering activities in K–12 educations. Given that engineers often work in teams and communicate with customers socially and collaboratively (NAE & NRC 2009; NRC 2012), students also have the opportunity address their scientific challenges while dealing with the iterations of questioning, planning, developing, evaluating and redesigning (King & English, 2016). Rehmat and Owens (2016) found in their research that combining literacy and mathematics with engineering makes learning more comprehensive, supports students' learning throughout the engineering design process and exposes them to real-world problem-solving skills. With the integration of engineering, students are able to apply EDP to solution of real-world problems (NAE & NRC, 2009). Next Generation Science Standards (NGSS) identifies three main components that reflect the iterative processes typically identified in previous literature (NRC, 2012). These are the following: a) clearly define and limit engineering problems in terms of success criteria and limitations or limits given; b) evaluate those who hope to design solutions by initially producing possible solutions and then identifying those that best meet the criteria and constraints of the problem; c) optimize the solution by systematically testing, improving solutions and developing the final design by trading out less important features. Several frameworks for describing engineering design are in literature (Denson, 2011; English, 2016; Hynes et al. 2011; Lucas, Claxton & Hanson, 2014). As an iterative process, engineering design often includes (a) problem determination (understanding problem limits, determining target and problem constraints), (b) generating ideas and planning, (c) design and building (sketch design, considering possible results, designing the product transformation), (d) testing and reflecting the analysis to results (controlling achievement of the target and meeting the constraints), (e) redesigning and reconstructing (reflecting on initial design, considering developments) and (f) communicating the design and construction processes. In this study, we use Moore and colleagues' (2013) engineering design process as a context for developing science, mathematics and technology concepts.

2. Methods

The case study, a qualitative research approach, was used in the study. A case study examines a timing system or a case depth using multiple data sources in the environment. The case may be a program, an event, an activity or a group of individuals limited by time and place (McMillan & Schumacher, 2010). In this section we describe the participants, data collection tools and analysis, engineering activity and implementation process. These are described below.

2.1. Participants

The participants in the study were thirty primary school teacher candidates (average age is 19) from second class at university. "The Controllable Switch" module is about primary school subjects and learning outcomes related to science and mathematics school curriculum. Participants were selected from primary school teacher candidates to provide them with STEM training for their future work as primary teacher.

2.2. Data Collection Tools and Analysis

This study used audio and video recordings and engineering design notebooks (EDN) as data collection tools. In addition, ethnographic content analysis was used to document and understand the communication of meaning as well as to verify theoretical relationships. A distinctive characteristic of ethnographic content analysis is the reflexive and highly interactive nature of the investigator, concepts, data collection and analysis (Altheide, 1987). An ethnographic document analysis is based on principles of qualitative data collection and analysis. To gain a richer understanding of the use of data collection tools during the iterative process, we included five focus groups for EDN's analysis complemented by ethnographic analysis. Ethnographic analysis provides opportunities to interpret patterns seen and heard in student-student conversations in the classroom (Creswell, 2002). Therefore, the analysis provided a unique picture of the learning that occurred during group conversations. During the activities, our presence in the classroom allowed us to make observations about how students apply STEM concepts while creating the controllable switching device that provides a starting point for analysis.

2.2.1. Audio and Video Recordings

All recordings were fully transcribed by the researchers. The researchers examined and analysed the video images of the students in the groups at different times. Concurrently, students' voice records were analysed at different times by the researchers. The communication between the students was determined to solve the given problem and to make the design.

2.2.2. Engineering Design Notebook

The engineering design notebook (EDN), developed by the researcher, was used as the main course material for design-based science education. The students in the study group did not use any printed materials other than these documents (e.g., a textbook and a workbook) during the implementation process. Throughout the practice, students made various drawings on these documents, filled decision matrices, expressed their reflective thoughts and created answers for research questions. Therefore, these documents that provide comprehensive information for different steps of the research encompass the main qualitative data source of this research project. In addition, these documents, which comprise the basic course material for the students, reflect the teaching in stages. Because of this feature, the EDN is a guide document for learning engineering design. An example of the EDN is shown under Figure 1.

Figure 1. Engineering design notebook

2.3. The Engineering Activity

2.3.1. Engineering Design Process

According to Moore et al. (2013), good STEM integration curricula should include motivating and meaningful context, engineering design tasks, opportunities to learn from failure and redesign, student-centred pedagogies, evidence-based reasoning and communication and teamwork skills. And Moore and colleagues' (2013) improved their engineering design process (EDP) and this process includes six steps: define, learn, plan, try, test, and decide. This EDP provides opportunities for students to follow an iterative method to solve engineering design challenges and produce several solutions for the problem. These steps are explained below.

The definition step seeks to determine what the problem is, why client wants to solve the problem and what criteria and constraints are required for the product to be defined. The learning includes pre-learning what science and mathematics knowledge is needed for the project. In the planning step, drawings and plans are made. In the trial stage, the prepared plans are tested. In the testing step, the products they have created are tested, and data is collected and analysed. In the decision-making step, students must decide whether the product meets the criteria and restrictions. If the created product does not meet the criteria and restrictions, they must go to the redesign section to rebuild the product. In redesign, the deficiencies are identified, and the product is redesigned. The restriction is limit of the product. For example, a criterion can be to develop a system that can change bulb brightness according to this implementation process. The fact that the client does not provide additional material is a restriction. It is also a criterion for each restriction.

2.3.2. Development of the Controllable Switch Module

We created an electric engineering activity that required students to design and build an electrical instrument that could control current intensity. This electrical activity has been determined in an engineering context where students are introduced to the work of electrical engineers through activities such as designing basic electric circuits and using different electrical tools. Naturally support students' acquisitions, since the targeted STEM disciplines (Table 1) are related to knowledge and skills for the implementation of the engineering design process and Controllable Switch Module (CSM) is structured to support the students' acquisition. CSM built on students’ existing science, technology, engineering and mathematics knowledge as well as the primary school learning acquisition.

Table 1. Science, Technology, Engineering, Mathematics Acquisition Related to the CSM.

STEM Areas	Acquisition
Science	1. Knows what simple electrical circuit elements are. 2. Knows the function of simple electrical circuit elements. 3. Can establish a simple electrical circuit. 4. Knows what resistance is. 5. Knows the effect of resistance on electrical circuit. 6. Knows that the longer the cable length, the less the bulb brightness decreases as the resistance increases. 7. Knows that as the cross-sectional area of the cables increases.
Technology	1. Knows that all the materials they use are technological products. 2. Knows that it is a technological product that facilitates the engineering design process.
Engineering	1. Can think like an engineer. 2. Can find out what the problem is like an engineer. 3. Knows the necessary science and mathematical connections to create the product like an engineer. 4. Makes plans and drawings of the product to be created like an engineer. 5. Tries to draw like an engineer. 6. Tests the experiment like an engineer. 7. As an engineer, he/she decides the prototype (product) and knows that the product that does not meet the criteria and constraints in the decision-making stage will be re-designed.
Mathematics	1. Can analyse the data. 2. Knows to make numerical measurements. 3. Knows how to make graphic drawings. 4. Knows that there is an inverse proportion between the data, one of which increases and the other decreases.

To develop the CSM, first the STEM fields were determined. Next, the CSM was designed and developed by the researchers. It is possible to state that CSM implementations carried out all of the acquisition. Finally, scenarios were prepared by the researchers (see example shown in Figure 2). All scenarios were sending to students to solve the problem situation at different steps of EDP. Students then had to determine the problem and the criteria-restriction from the scenarios.

> The subject of this week's meeting with the commission members of the energy and heat saving chairman is electricity saving. You are one of the members in this commission. The main reason for you to encounter this issue is to develop a system that can change the brightness of the bulb in homes. If this system is developed, the head of energy and heat saving will have achieved its purpose. it will also be to design a product suitable for this problem with the same materials it distributes to the members that you want. In addition, the commission will not provide any additional materials and the engineer who approaches the desired with the materials at hand will be selected both as an award and engineer of the year. Come on, design the desired product.

Figure 2. One of the scenarios

The materials given to each group in order to perform this activity are shown in Figure 3.

> 1 lamp holder, 3 mA and 5 mA bulbs, electrical cables, battery bearing, 2 batteries, 1 reversible key, chrome-nickel and copper wire of different lengths and different cross-sections of chrome-nickel and copper wire, 2 pieces of salmon, 1 hollow cable 10 cm long, 1 silicone gun and sugar box.

Figure 3. Materials

In this activity, students designed a prototype for a controllable switch instrument that could be marketed for public use. Students were introduced to all electrical materials with this activity.

2.3.3. Forming Cooperation Groups

Cooperation is the process of working together to achieve common goals. Individuals who cooperate seek useful results for themselves and all other group members. Cooperative learning is the instructional use of small groups so that all students work together to maximize their own and each other's learning (Johnson & Johnson, 2012). Before the implementation process, the students were divided into six groups with five people per group. Gender and achievement status were taken into consideration in determining the groups. Group work is very important in this process. Students had been informed that work together and combine their answers into a group. Group rules were announced to the students. If groups had time, they could create a group name. The researchers immediately warned the students who did not comply with the group rules and stated that they should follow the rules.

2.4. Implementation of the Process

Before implementation, researchers talked about STEM to students and what the students should pay attention to during the application process. Each student had a special notebook. In this notebook, there were sections where they could write both their own ideas and group ideas. In addition, the first page of the notebook was attached to the engineering design process, and the design was arranged so that the students could the design at any stage and at any time. The researchers left this book on the tables of the groups at the beginning of each lesson and collected it at the end of the lesson, pasting the questions and scenario of the lesson to be taught in the next lesson as well as all scenarios developed by the researches. This book contained preliminary information about the subject, ideas of group members and individuals, design drawings and the correct information obtained after the experiments. In this process, the aim is for the student to determine the necessary information from his own experience using the design process, instead of learning the information from different sources by doing research. Draft of the STEM integration is shown in Table 2.

Table 2. Draft of the STEM integration process

Lesson	Time	In class interactions process
Introduction to engineering and define the problem situation	30 min.	Students are introduced to the engineering problem situation with a scenario. For example, "Who is an engineer? What does an engineer do? What is the scenario about? What is the problem?"
Introduction to basic electric circuit element	30 min.	Battery, bulb, key, conducting wire, resistance; how to connect these elements to make a basic electric circuit.
Effect of different wires in the circuit	30 min	Use different lengths and cross-sections of chrome-nickel and copper wire.
Brightness of the bulb	30 min	Factors that affect the brightness of the bulb: type of the wire, the length of the wire, value of resistance, number of batteries
How to plan for the solution	35 min	Design and build a controllable switch instrument prototype. Students justify their design choices using data and evidence from their experiences in previous lessons.
Testing and building the instrument	40 min	Test the prototype for an appropriate solution and build the best design of the controllable switch instrument.

Students sometimes experience failure, but as a result of their failure, it is important that they experience ways to access the right information. At the start of the implementation process, students were provided with a scenario and asked to solve the problem. The students learned about and utilized a model of the engineering design process: define, learn, plan, try, test, and decide. The unit also included eight science and engineering practices recommended by the NGSS: defining problems; developing and using models; planning and carrying out investigations; analysing and interpreting data; using mathematics and computational thinking; designing solutions; engaging in an argument from evidence; and obtaining, evaluating, and communicating information. Researchers always asked the students, "Which phase of the engineering design process are we in right now?"

3. Results

Our presence in the classroom during the activities enabled us to make observations about how students applied STEM concepts while building the CSI, providing a starting point for the analysis.

RQ 1: *What are primary school teacher candidates' views on what engineering is?*

In the defining step of the application process, questions about what the engineers do, the branches of science the engineers used and how the engineers solved the problems were written in the notebook. The students were asked to write their individual answers first, then to exchange ideas with the group and to write down joint group decisions.

Regarding the question of what the engineers do, Group 1 stated, "the engineer is the person who makes the calculations using the necessary technological, mathematical and science fields in the planning and production stages of the projects that will be produced considering the needs of the society in every field of life and designs the most efficient form of the project to be produced as a result of these calculations". Group 2 stated, "in line with the supply and demand of the society, technology, science, mathematics by taking advantage of the areas of people who produce solution-oriented ideas m". Group 3 stated, "makes a scientific analysis of a new product to be revealed. The task is to minimize the margin of error in the product by conducting scientific analyzes". Group 4 stated, "the engineer is the person who aims to create a structure and specializes in this field. Produces products, designs and solutions that benefit the society". Group 5 stated, "produces a product by utilizing science, mathematics, technology and various sciences in order to facilitate human life".

For the question about what discipline of science engineers use, Group 1 stated, "math, science, geometry, chemistry, physics, philosophy". Group 2 stated, "science, mathematics, physics, sociology". Group 3 stated, "mathematics, physics, geography". Group 4 stated, "philosophy, mathematics, physics, geometry". Group 5 stated, "mathematics, geometry, science".

For the question of how engineers solve problems, Group 1 stated, "develop technologies by detecting problems and designing accordingly". Group 2 stated, "firstly engineers identify problems and produce the necessary solution by considering the needs of the society and why this problem is caused and how to collapse”. Group 3 stated, “by finding the source of the problem, they develop and analyze possible solutions”. Group 4 stated, “after finding out what the problem is, they make observations for the solution”. Group 5 stated, “they determine the problem situation and collect information about it afterwards, they plan and design projects and find solutions”.

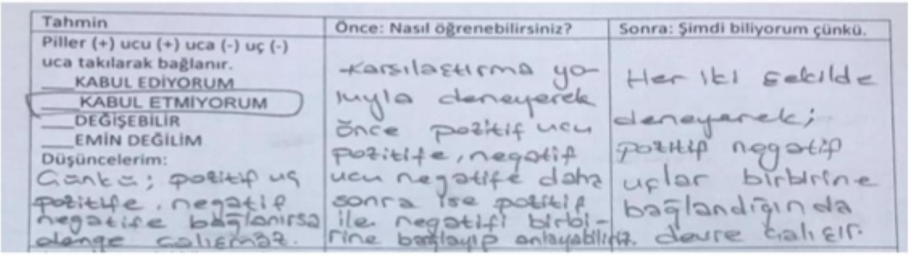
RQ 2: *Can the candidates explain the problem situation for the given scenario?*

In this lesson, students will be in the problem scoping section of the engineering design process, specifically defining the problem. In this stage, students will first be introduced to the engineering problem through a client letter. The problem statements given in the client memos purposefully do not provide all the information necessary to solve the problem. Based on the information from the client, students will then define the problem in terms of what the problem is and why it is important, who are the client and end users, what are the criteria and constraints as well as defining what other information they may need in order to solve the problem.

Regarding the question of what the client’s problem is that needs a solution, all groups stated, “electric energy is used too much and therefore the bulb brightness should be reduced”. For the question of why this is important to solve, all groups stated, “to save electricity and preventing excessive use of electricity”.

RQ 3: *Is there any difference between pre-service teachers' pre-knowledge and final knowledge about the simple electrical circuit after the experiment?*

Before beginning their design challenge, students learned background information on simple electrical circuit elements. This would help them make decisions about the types of materials that are appropriate for their design solution. In this lesson, students worked through four stations where they examined different aspects of the electrical circuit: 1) test the connect the poles of the batteries; 2) determine if the brightness of the bulb depends on the bulb's resistance; 3) determine whether the length of the wire has an effect on the brightness of the bulb; 4) determine whether the cross-sectional area of the wire has an effect on the brightness of the bulb. All students wrote their EDN; some examples are shown below (Figure 4-7).

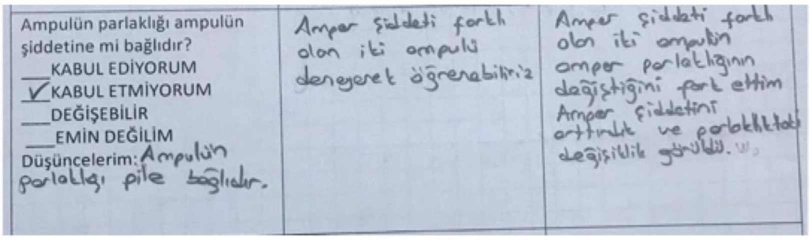


Tahmin	Önce: Nasıl öğrenebilirsiniz?	Sonra: Şimdi biliyorum çünkü.
Piller (+) ucu (+) uca (-) uç (-) uca takılarak bağlanır. ___KABUL EDİYORUM [✓ ___KABUL ETMİYORUM] ___DEĞİŞEBİLİR ___EMİN DEĞİLİM Düşüncelerim: Çünkü; pozitif uç pozitife, negatif negatife bağlanırsa olenge çalışmaz.	Karşılaştırma yoluyla deneyerek önce pozitif ucu pozitife, negatif ucu negatife daha sonra ise pozitif ile negatifi birbirine bağlayıp anlayabiliriz.	Her iki şekilde deneyerek; pozitif negatif uçlar birbirine bağlandığında da devre çalışır.

The positive end of the batteries connect to the positive end, the negative end to the negative end	Before the activity, how could you learn?	After the activity, what have you learned?
I accept ….. I don’t accept X I’m not sure … Because; if the positive end is connected to the positive end, the negative end is connected to the negative end, the circuit will not work	By trying by comparison, we first connect the positive end to the positive end, the negative end to the negative end and then the positive and negative.	The circuit works when the positive and negative ends are connected together.

Figure 4. Examples from the EDN, “test the connect the poles of the batteries”.

In the section containing the directives, “Prediction; before the activity, how could you learn?” and “After the activity, what have you learned?” in the engineering notebook (Figure 4), students were first asked to guess the given expression within their own prior knowledge. Students who explained their predictions then suggested how to determine whether this statement was true or not. After this stage, materials were placed on the tables, and students are allowed to experiment with the given proposal. At the end of their experiments, they decided whether the proposition was true or false and received information about this subject.

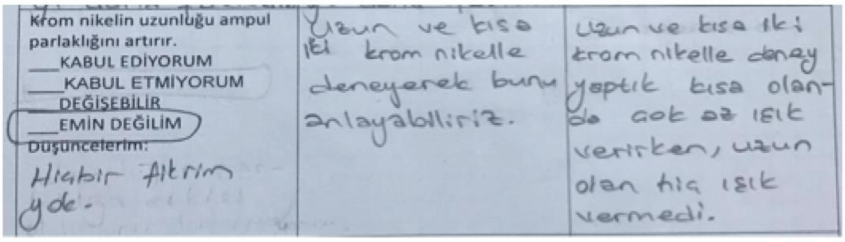


Ampulün parlaklığı ampulün şiddetine mi bağlıdır? ___KABUL EDİYORUM ✓KABUL ETMİYORUM ___DEĞİŞEBİLİR ___EMİN DEĞİLİM Düşüncelerim: Ampulün parlaklığı pile bağlıdır.	Amper şiddeti farklı olan iki ampulü deneyerek öğrenebiliriz	Amper şiddeti farklı olan iki ampulün amper parlaklığının değiştiğini fark ettim Amper şiddetini arttırdık ve parlaklıktaki değişiklik görüldü.

The brightness of the bulb dependent on the resistance of the bulb	Before the activity, how could you learn?	After the activity, what have you learned?
I accept ….. I don't accept X I'm not sure … Because; the brightness of the bulb depends on the battery	We can learn by trying two bulbs with different current intensity.	It is ethical to notice that the brightness of the two bulbs intensity changes with different current. We have seen that the brightness of different resistant bulbs is different.

Figure 5. Examples from the EDN, "determine if the brightness of the bulb depends on the bulb's resistance".

The question of whether the brightness of the bulb is dependent on the resistance of the bulb was presented to the students. As shown in Figure 5, the student did not accept this statement because the student thought that the brightness of the bulb depends only on the battery. The student thought that this question could be answered by connecting two different bulbs to the circuit. However, as a result of experiment trials, the student observed that the brightness of the bulb varies depending on the type of the bulb, the number of batteries in the circuit and the length of the connecting cables.

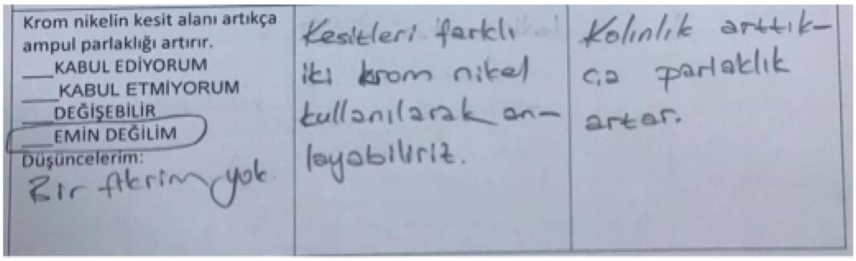


Krom nikelin uzunluğu ampul parlaklığını artırır. ___KABUL EDİYORUM ___KABUL ETMİYORUM ___DEĞİŞEBİLİR [✓ ___EMİN DEĞİLİM] Düşüncelerim: Hiçbir fikrim yok.	Uzun ve kısa iki krom nikelle deneyerek bunu anlayabiliriz.	Uzun ve kısa iki krom nikelle deney yaptık kısa olanda çok az ışık verirken, uzun olan hiç ışık vermedi.

Length of chrome nickel wire increases bulb brightness	Before the activity, how could you learn?	After the activity, what have you learned?
I accept I don't accept I'm not sure X Because; I have no idea	we can understand by trying with long and short wires	we experimented with two long and short chrome nickel wires, while the short one gave light, the long one did not give any light

Figure 6. Examples from EDN, "determining whether the length of the wire has an effect on the brightness of the bulb"

According to Figure 6, the students learned that this sentence was wrong by trying chrome-nickel wire of different lengths and finding that the bulb brightness decreased as the length of the chrome nickel wire increased. Students mathematically stated that as the length of the chrome-nickel wire increased, the brightness of the bulb decreased, which is an inverse proportion.



Krom nikelin kesit alanı artıkça ampul parlaklığı artırır. ___KABUL EDİYORUM ___KABUL ETMİYORUM ___DEĞİŞEBİLİR [✓ ___EMİN DEĞİLİM] Düşüncelerim: Bir fikrim yok.	Kesitleri farklı iki krom nikel kullanılarak anlayabiliriz.	Kalınlık arttıkça parlaklık artar.

The brightness of the bulb increases as the cross-sectional area of the chrome nickel wire increases	Before the activity, how could you learn?	After the activity, what have you learned?
I accept I don't accept I'm not sure X Because; I have no idea	We can understand the cross-section areas using two different chrome nickel wires	Brightness increases as the cross-sectional area increases

Figure 7. Examples from EDN, "determining whether the cross-sectional area of the wire has an effect on the brightness of the bulb".

The student, who did not have an idea about the cross-sectional area of the wire and how the brightness of the bulb will change, considered using wires with different cross-sectional areas to determine this. After the experiment, the student saw a direct proportion between the cross-sectional area and the bulb's brightness: the bulb's brightness increased as the cross-sectional area increased, and the bulb's brightness decreased as the cross-sectional area decreased. As a result of these activities, students acquired the conceptual understanding necessary to build the product.

RQ 4: *Are there any differences between the pre-service teachers' individual design ideas and the group design ideas?*

The students sketched the product that they will create individually, then brainstormed with their group, drew the design that they decided on and stated why their designs would work. The design drawings of each group and the personal design drawings of one of the students are shown below (Figure 8-11). In this part of the EDN, students were first asked to draw their designs individually and to state their thoughts on why this design would work. After each student wrote their own design ideas, they discussed their drawings and made a different drawing to develop and build CSI.

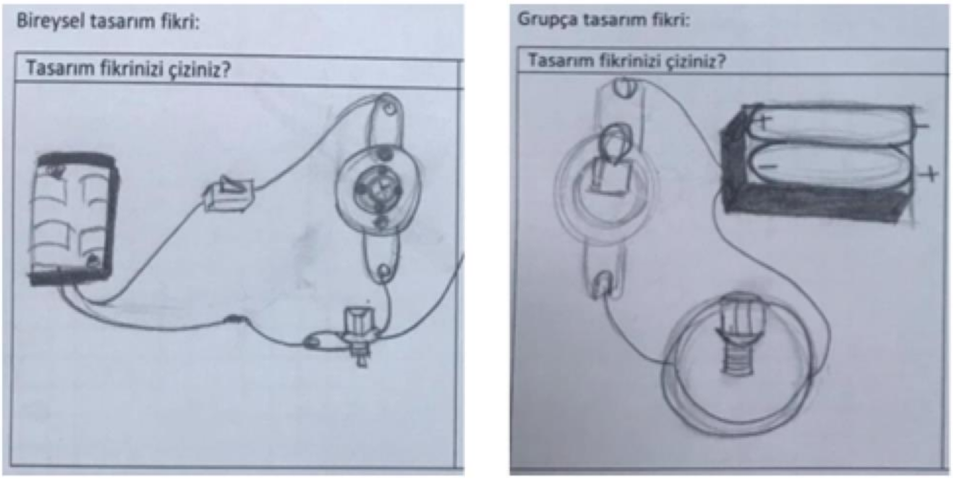


Figure 8. Personal (left) and group (right) design drawings of Group 1.

As seen from Figure 8, the key in the individual design differs from the key in the group design. Because students first worked on their individual design and then worked on group design. The students use circuit with a round key model in the group design, which is different from the key included in the individual design. First the students in-group draw the design individually and than all students in-group work together and drawing just one design. Furthermore, group design was more real like than individually design. The conversation between the students until they realize such a design are as follows:

S1: Why did our light bulb did not burn?
S3: I wonder if we connected the batteries incorrectly.
S4: Ok, we have to replaces the batteries.
S5: Let's punch the box as well (S5 and S4 together get the box out)

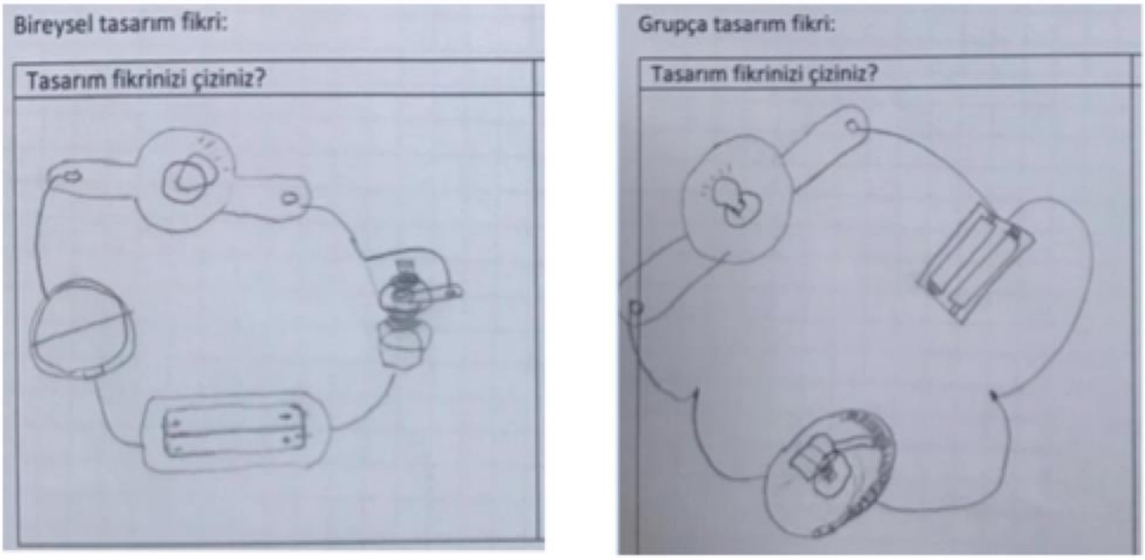


Figure 9. Individual (left) and group (right) design drawings of Group 2.

Individual: I think the brightness will change, but I was not sure of this design.

Group: By wrapping the thin nickel-chrome wire around the cable, we get a long way and we think it will work.

As seen from the Figure 9, the key in the individual design differs from the key in the group design. In the design made by the group of students who think that the key included in the individual design will work, a round key model that is created differently is seen in the group design. First the students in group draw the design individually and than all students in group work together and drawing just one design. Furthermore, group design was more real like than individually design. The conversation between the students until they realize such a design are as follows:

S1: The bulbs are different so we will try all bulbs.
S3: Let's start with the low amp bulb first.
S1: As design, we will remove this round box as crazy and one of them will serve as a key.
S2: We need a nail then.
S5: Not a nail or a pin.
S4: We will adjust the brightness of the bulb by wrapping the wires around it.
S4: Then we will put this key in this box.
S1: We will connect the wire wrapped in the cable we prepared to the end of this switch, if we want to increase it, we will turn it to the left.
S2: So how do we connect that wire there?
S3: Shall we pierce the box from below?

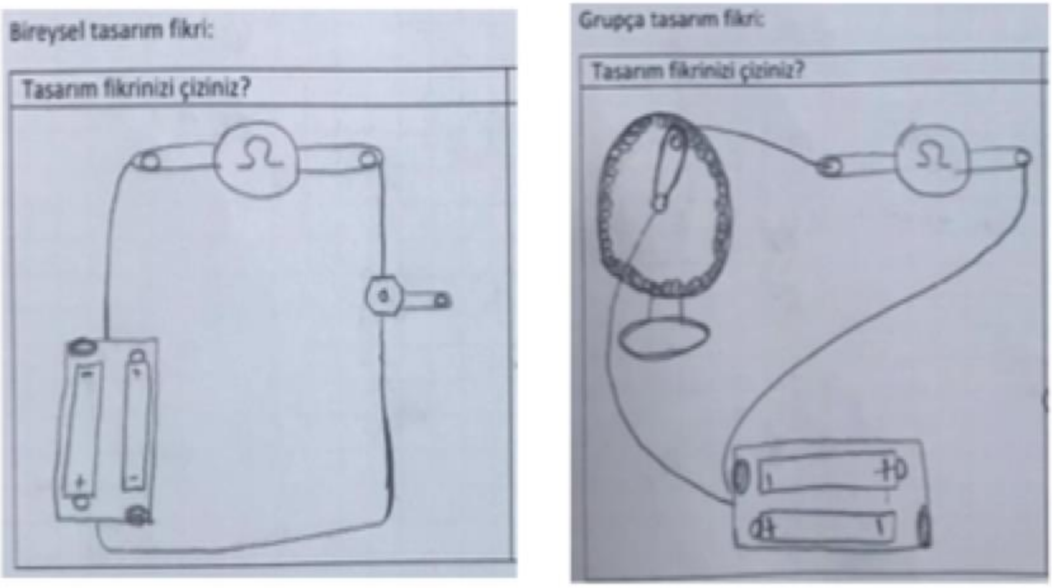


Figure 10. Individual (left) and group (right) design drawings of Group 3.

Individual: It can work if we add a key in the design I made as in the figure

Group: If we realize the design with fine chrome-nickel wire, we get the desired result as in the figure.

As seen in the Figure 10, the key in the individual design differs from the key in the group design. In the design made by the group of students who think that the key included in the individual design will work, a round key model is created in a different way. The conversation between the students until they realize such a design are as follows:

S4: You don't have to use all the materials.

S3: No, it does not give light, and now because of the high resistance, let's try.

S1: I think we need to use thick copper wire

S3: Yes, I have to connect this to the circuit now. But first I have to fix the cable or wire.

S3: Is the key touching the wire?

S2: Yes contact.

S3: If we have to separate the wrapping again, no problem.

S3: When we increase the resistance, it does not light up, but when we decrease the resistance, the bulb lights up.

S1: The wire we wrap in the cable inside the toy box.

S5: Give me the silicone and let me fix it (the group that completes its designs has fixed it with silicone.)

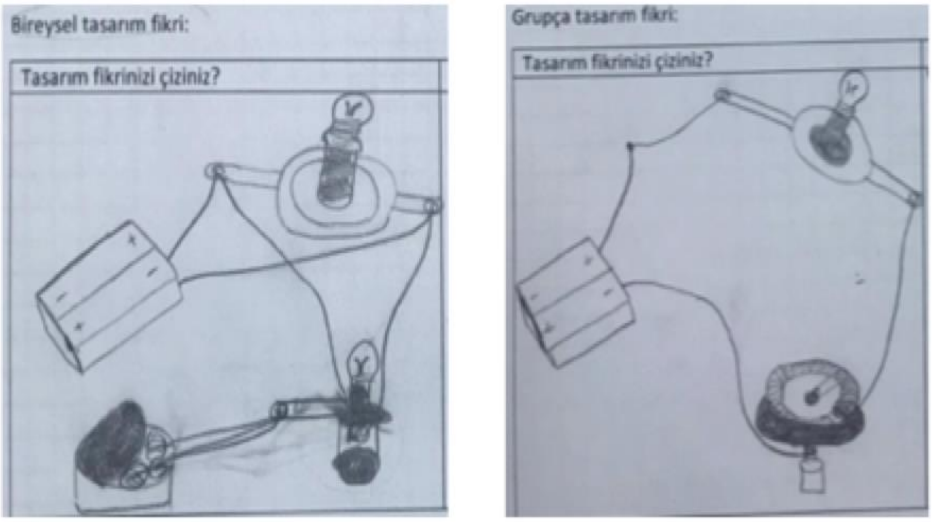


Figure 11. Individual (left) and group (right) design drawings of Group 4.

Individual: I think the brightness will change with this system.
Group: We change the brightness of the bulb with this method.
As seen from the Figure 11, the key in the individual design differs from the key in the group design. Before the students discussion among themselves they draw the design individually. And after the all drawings students make a decision about drawings and finally they draw just one drawing. The talks between the students in group 4 , until they realize such a design are as follows:

S1: We have to cut a little bit of this long cable given to us.

S1: Now you connect this cable to the battery.

S1: When we wrap this wire so tight, the resistance increases.

S1: Now we have wrapped the wires that we have in the cable, we will connect all of them to the battery.

S1: This wire will be resistor as you open the switch; the wire length will increase or decrease.

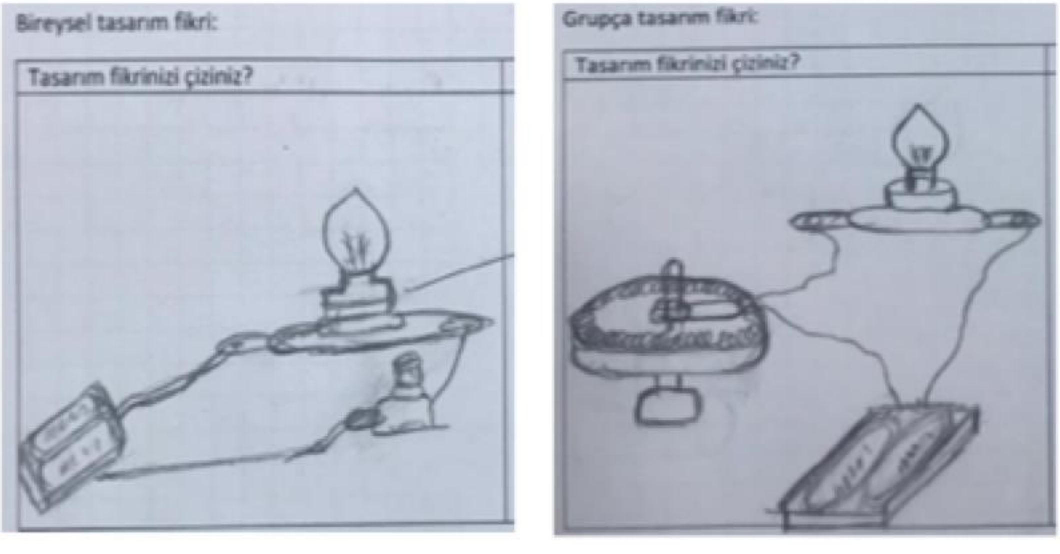


Figure 12. Individual (left) and group (right) drawings of Group 5

Individual: I used the key in this design and I think I can change the brightness of the bulb with this key.

Group: If we coil the thin chrome-nickel wire around the cable and install the circuit accordingly, the brightness of the bulb will change.

As seen from the Figure 12, the key in the individual design differs from the key in the group design. The conversation between the students until they realize such a design are as follows:

S2: (it connects the two wires, which take the hollow cable from the materials supplied, to the two wires), this is too long.

S1: The length should be small.

(S2 and S1 wraps the wire that he has identified on the cable they have doubled)

S2: Let the range be a little wide.

The students tested their designs to see if their design ideas worked. After the trials, the best decision was made about the number of turns of the wire (the length of the wire used), how the circuit would be connected and the way the switch was connected in the circuit, and the design has been realized. The groups that had difficulty preparing the key correctly and had difficulty in how it was connected to the circuit were allowed to review the design ideas again. Returning to the redesigning stage, the groups made different designs to eliminate their mistake, tested their designs and made the best decision.

4. CONCLUSION

In this study, primary school teacher candidates applied a STEM activity utilizing the engineering design process. In all approaches related to integrating engineering in science education, it is provided that they carry out the design development process while generating solutions to daily life problem (Moore et al. 2014). In this process, rather than running a general problem-solving process, the aim is to think like engineers (Dym, 1994).

The engineering design notebooks used by teacher candidates during the development of the design that were examined. According to Wendell et al. (2019), design notebooks work as an epistemic tool by coaching students to organize their design thinking into different types of notebooks. For this purpose, together with the STEM activity, the answers of the pre-service teachers to the questions in the steps of engineering design processes were also included. In this research, the group evaluated the answers of the teacher candidates, but individual answer examples were also included in the questions in the learning step, one of the engineering design processes, as well as in the planning step. The aim was to compare the students’ previous knowledge before the experiments and the students’ next knowledge after the experiments. Opinions of teacher candidates about engineering were examined, determining that each group had different answers. STEM education enables students to work in groups, transferring their thoughts to each other; Niess (2005) stated that the implementation of STEM education increases the cooperative learning skills of individuals.

In the identification step, the initial stage of the engineering design process, prospective teachers were given a scenario and asked to determine the problem based on the scenario. In STEM education applications, it is important to start with engineering problems, namely design problems, because it is important to learn about how engineering can address daily life problems (Leonard, 2004). Engineering design problems are also an effective way to foster science learning in STEM education. In addition, individuals learn information about the relevant discipline while solving engineering problems and develop their design skills within the process (Kolodner, 2002).

In the learning step, pre-service teachers obtained the necessary information to prepare their designs. However, at this stage, the teachers were prevented from using any external sources (e.g., internet, library, smart phone). The pre-service teachers made different experiences with the tools and equipment provided to them and answered the questions with the information they gained as a result of their experience. At this stage, prospective teachers were expected to make mistakes, but building off of their mistakes enables them to gain experience and in-depth knowledge about the subject. Additionally, they were expected to learn more about the properties of the elements in the electrical circuit and reach more applicable results from their designs.

As a result of working with a group, a central feature of STEM education, the importance of peer education has emerged. There are significant differences between the design ideas that teacher candidates made individually and the ideas they made by discussing with the group and exchanging ideas. First the students in group draw the design individually and than all students in group work together and drawing just one design. Furthermore, group design was more real like than individually design. The emergence of different thoughts in their conversations with each other adds a different dimension to the design. In Figure 13, the effect of the adjustable switch designed by prospective teachers on the brightness of the bulb is evident. It is apparent that the brightness of the bulb decreases by turning the switch clockwise and increases by turning the switch counter-clockwise.

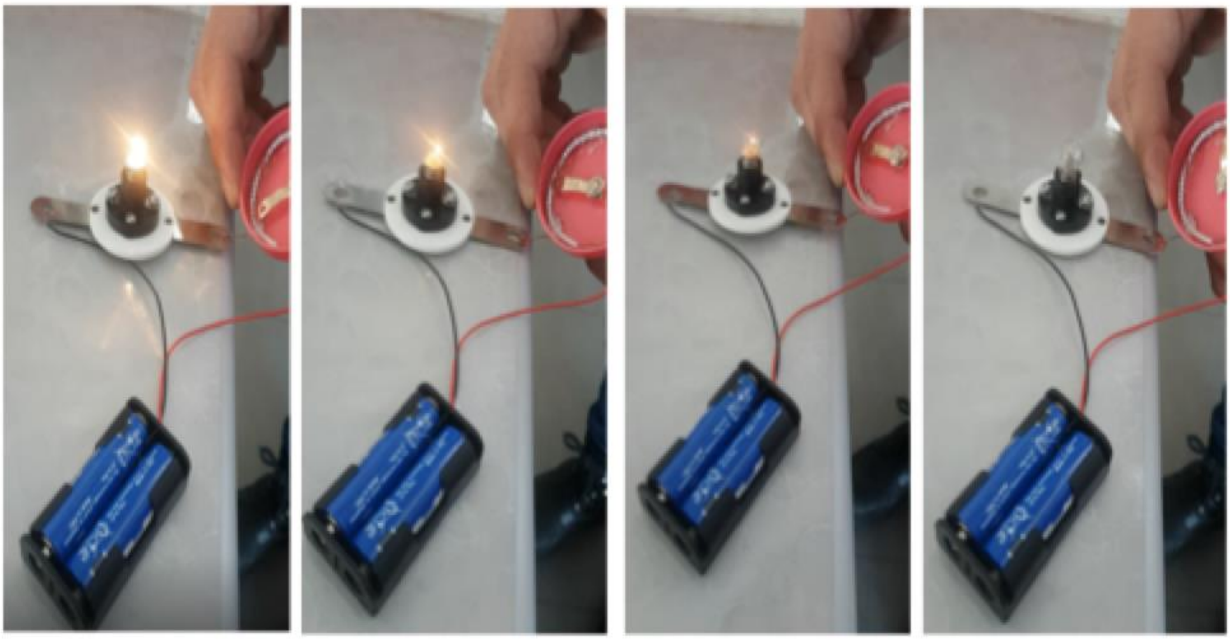


Figure 13. The effect of the adjustable wrench designed by prospective teachers on the brightness of the bulb

As a result of this research, pre-service teachers had an opportunity to experience engineering design-based science education focusing on electricity saving, which is a problem they may encounter in real life. Furthermore, according to Tran (2018), integrating technology and STEM activities into students' education in lower grades can greatly impact their career choices in life.

It can be accepted as an indication that there is a need to provide examples of activities in terms of STEM education, teachers having difficulties at the points of activity practices and not knowing how to do their applications. In this study, presenting the activity in detail to reduce these concerns was shown to be beneficial for researchers, teachers and prospective teachers. It is also important to introduce an application related to the new STEM education approach to the access of researchers, teachers and prospective teachers who are interested in the field. Therefore, developing appropriate sample activities that can be used in STEM education can make an important contribution. However, in order for teachers to apply STEM programs to be equipped with knowledge and skills, STEM education practices should be applied to students in the education faculties of universities and in-service trainings should be included in the in-service trainings for the current teachers to gain the same experience.

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Authors

Nilüfer OKUR AKÇAY, Ağri İbrahim Çeçen University, Ağrı (Turkey). E-mail: nilokur-7@hotmail.com

Ezgi AKKUŞ ÇİTFÇİ, Ağri İbrahim Çeçen University, Ağrı (Turkey).