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Examination of High School Students' Engineering Design Skills: Example of Electromagnetism*

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ABSTRACT
In the secondary and high school science program implemented in Turkey in 2018, the importance of engineering and design skills is underlined under domain-specific skills. The purpose of this study, in which case study method, one of the qualitative research methods, is used to examine the engineering design skills of high school students within the scope of a real-life problem. In the study, an engineering design-based problem of making electromagnets was given to high school students, and the study was carried out five weeks. During the solution process of the problem, the students were expected to accept themselves as an engineer and solve the given daily life-based problem from this perspective. The study group consists of 28 volunteer high school students attending at the 11th grade in a state high school. The data of the study (written documents) were evaluated by the researchers with a content analysis approach. According to the results, it was determined that the students were able to deal with the real-life problem from different dimensions and come up with appropriate solutions. In addition, when the students' drawings were examined, it was observed that they exhibited their creativity. Still, it was observed that the applicability of these drawings was low and far from technical details. Another finding is that they are not successful in using scientific knowledge and making calculations.

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Introduction

It is important that the knowledge of science, technology, engineering, and mathematics (STEM) is increasingly needed in today's societies. The purpose of the practice of STEM is to increase the competence of people at work and/ or in life and more generally meet social demands related to technology. For this reason, the STEM approach should be applied starting from primary school to make intellectual-and-skill-based investments in a nation. According to Ülger and Çepni (2020) STEM education is seen as a key factor to increase the number of qualified individuals in the science, mathematics, technology, and engineering fields. For it is importance in terms of the future welfare of societies, from a different viewpoint, it is regarded as a key to all students' success at many works, which have not been conceptualized yet in the 21st century (Breiner, Harkness, Johnson, Koehler, 2012).

The interdisciplinary or integrated STEM education can be explained as a combination of disciplines, can be used to understand examples in the real world, and can be useful to solve problems and (Siekmann and Korbel, 2016). Workforce Report STEM (2014) adopts the opinion that STEM education is more than the appropriate integration of four disciplines and states this opinion as "it covers real-world problem-based learning".

Engineering constitutes one of the four branches of the STEM discipline. Engineering requires the application of content knowledge and cognitive procedures to design complex systems, analyze them, and eliminate their problems to meet the needs of a society (Brophy, Klein, Portsmore and Rogers, 2008). In this respect, especially through the integration of engineering, students should be informed more about the existence and the role of engineering in society and apply engineering design processes to real-life problems (National Academy of Engineering (NAE) and National Research Council, 2009).

According to Carr and Strobel (2011), it is important to integrate engineering into secondary school education level; for this reason, schools need to integrate the contents of mathematics and science meaningfully and perform problem-based, applied and inquiry-based activities. Moreover, dealing with engineering design processes as a part of secondary school curriculum might also develop students' understanding of the basic concepts and principles of a discipline and problem-solving abilities to a considerable extent (Borgford-Parnell, Deibel and Atman, 2010; Brophy et al., 2008; Diefes-Dux, Zawojewski, & Hjalmarson, 2010; English and Mousoulides, 2011; Stoner, Stuby and Szczepanski, 2013).

STEM teaching can be performed starting from all grades. However, engineering discipline is a very important transition point for secondary school students, as they state that mathematics becomes difficult, they get less help from their teachers and parents. They are more worried about using technical materials in the secondary school years (Adelman, 1998).

Engineering design processes:

Design is a combination of design thinking processes and skills. Design thinking is a way of finding new solutions for human needs by using tools and generating thoughts. It depends on active problem solving and the ability of the person to create effective change (Kelly and Kelly, 2013). Plattner (2015) stated that the basic components of the design-based thinking process as being human-centered and action-oriented through giving importance to the process and emphasized that the five basic stages of design-based thinking as empathizing, defining, thinking, prototyping and testing. Engineering processes, in general, include design elements, while the design thinking model consciously integrates an empathy component that designers should consider the needs and values of the people they design. As design thinking focuses on student empowerment and actions, it is a powerful tool to meet the needs of 21st-century learners by providing a human-based structure for problem identification and solution (Cook and Bush, 2018).

In the 21st century, importance is given to the application of innovative educational approaches to ensure the success of students, and one of the innovative approaches is design-based thinking (Çiftçi & Topçu, 2020; Lor,2017) In this context, engineering applications emphasize the engineering design process as it facilitates students' learning through problems adapted to the real world (Brand, 2020) and indicates the necessity of developing engineering design skills of students (Bozkurt Altan, Yamak, Kırıkkaya & Kavak, 2018; Özkızılcık & Cebesoy , 2020; Uysal and Cebesoy, 2020.) In addition according to Parmin and Sajidan (2019), designing skills that students have is a benchmark of their concept mastery.

According to Fan and Yu (2017), engineering design is complex decision-making and problem-solving process. In this respect, the problem-solving ability is needed in the engineering design process. Higher-level thinking abilities are essential for predicting the practicability of different solutions, evaluating results and finding appropriate solutions. For example, this kind of experience helps students appreciate and understand various engineering roles in shaping societies. Moreover, engineering design helps to understand mathematics and science principles and explains how to make success, motivation and the development of problem-solving skills contextual (Cunningham and Lachapelle, 2014). Due to these facts, National Research Council, NRC (2012) emphasizes that science and engineering practices need to be started in early grades and later be practiced from secondary school level to high school level.

According to Hynes, Portsmore, Dare, Milto, Rogers, Hammer, and Carberry (2011), the engineering design process is in the center of K-12 engineering. Here, the purpose is to teach students the fact that "rather than making or building something, which is a common mistake, engineering is related to the development of decision-making or the organization of thoughts to develop high-quality solutions and/or products to problems". Since engineering design focuses on multidirectional methods by which students can develop their abilities and tendencies to solve complex problems in real life, it has attracted great interest in the literature (English, Hudson and Dawes, 2013; Cunningham and Hester, 2007; Mehalik et al., 2008; Moore et al., 2014; Purzer et al., 2015).

There are also studies indicating the importance of students' planning process, an important component in their making designs to realize final products (Hynes et al. 2011). Aflatoony and Wakkary (2015) stated in their study that Canadian high school students have limited experience in design-based thinking and creative problem solving, and they concluded that design-based teaching, including the entire design process, can provide different benefits for students to transfer their knowledge to unfamiliar contexts. Vanscoder (2012) found that student's commitment to learning, their participation in applied, real-world projects, and design-based thinking in courses that use problem-based learning methodology encourage design-based thinking to increase their understanding of key subject areas. National Center for Technological Literacy (NCTL, 2015) states that the key to the education of students to become successful in this competitive global economy is to introduce them the engineering design skills and concepts helping them practice mathematics and science knowledge to solve real problems at an early age. According to Langman, Zawojewski and Whitney (2016), keeping students busy with design and engineering increases their capacity to adopt new thinking processes and alternative ways of seeing the world, seek for and inquire new problems, willingly struggle with the complexity of arising problems, and practice and develop solutions to problems. Here. the purpose is to have students get involved in important characteristics of the design process.

English and Mousoulides (2011) as well as Zawojewski et al. (2008) described the engineering design processes as the creation, application and adaptation of mathematical/scientific models to be used to interpret, explain, and predict the behaviors of complex systems and stated that the design process is in the center of engineering. Through the engineering design, students learn more than one idea or approach which is possible to be in the solution of complex problems, and a lot of materials and drawings can be used (International Technology Education Association (ITEA) 2000; Cunningham and Lachapelle, 2014). Schunn (2011) stated that the engineering design process naturally involves some creativity and multiple solutions.

Hynes et al. (2011) stated that the cyclical processes of engineering design should be regarded not as a set of strict rules to be followed, but as a set of guidelines to take into consideration in curriculum design and teaching in high school engineering which are specified in these cyclical processes as follows:

- Identify the need or problem,
- Research the need or problem
- Develop possible solution(s)
- Select the best possible solution(s)
- Construct a prototype
- Test and evaluate the solution
- Communicate the solution
- Redesign
- Complete

Haik and Shahin (2012) specified three kinds of the design process. a) Development design starts from an existing design, but the outcome might differ from the first product. b) New design is the most difficult level and requires creativity and imagination a lot. c) Adaptable design is related to the adaptation of existing designs. There are production branches where development practically ends. Hence, it is a kind of design where there is nothing left for a designer but generally to make little changes in the dimensions of a product. On the other hand, Haik and Shahin (2012), at the same time, stated that the design of a device or a system could be made in one of two ways, namely evolutionary or innovatively.

Howard et al. (2008) expressed it as four types of design outputs as original design, adaptive design, variable design, and routine design by generalizing the classification of design outcomes created by Pahl and Beitz (1996). Gero and Kannengiesser (2004) defined these outputs as follows (as cited in Wong & Siu, 2012):

Original design: Presenting an original solution to a known problem

Adaptive design: Adapting a known solution to a new problem

Variable design: Changing the properties of a known solution

Routine design: not creative in any direction.

Wong and Siu (2012) stated that it is possible to apply these categories to the designs made by students in design education.

It is not enough to contextualize only mathematics and science principles and promote design processes. The curriculum should also be inconvenient with this to develop students' engineering understanding. For this reason, the focal point of activities performed at schools is to include students in engineering design processes where they are to solve difficult but meaningful real-life problems. However, previous studies made on the secondary school level indicated that although some contributions could be made to interdisciplinary problems via regulations in programs, these expected contributions remained at an insufficient level (Brophy et al., 2008).

When the studies conducted in our country was examined, it was seen that the design-based studies were mostly at the secondary school level, within the scope of teachers' opinions (Pekbay et al. 2020; Harman & Yenikalaycı, 2021) or design-based studies are not often encountered at the high school level. Arık and Topçu (2020), in their meta-analysis study on engineering design processes, stated that they could not find a well-established tradition on how to conduct an engineering design process at the K-12 level in the current literature.

Purpose of The Study

Technological changes and innovations played a great role in considering engineering skills in school programs in Turkey, as it is in the whole world. In the Physical Sciences course teaching program, which put into practice in Turkey in 2018-2019, the importance of engineering and design skills was emphasized under field-specific skills. It was targeted to proceed them during high school education. This study aims to examine the engineering design skills of high school students in the context of a real-life problem. For this reason, answers to the following questions were sought in the study.

1. Can high school students identify issues in a real-life problem? What are these problems?
2. How can they find a solution to the given problem?
3. How do they support their solution proposals?

Method

Purpose of the Study

The study is a descriptive one in which the case study method, one of the qualitative methods, is applied. The case study includes the comprehensive and longitudinal examination of a single case or an event. It is a systematic way of looking at what is happening, collecting information, analyzing information, and reporting results (Davey, 1991). The case study allows one or a few special cases to be analyzed in-depth (Şimşek and Yıldırım, 2016). Therefore, this study, which is considered as an exemplary case study, examined how 28 high school students understood the problem by using their knowledge on magnetism and the engineering design process, how they offered a solution to the problem, and how they supported the solution proposals. The study was carried out by considering the case study steps specified by Yıldırım and Şimşek (2016).

Study Group

The study group consists of 28 volunteering high school students attending 11th grade in a state high school. A purposeful grouping method was used to determine the study group. In the purposeful group selection, criteria that are considered to be important for the research subject are determined, and it is thought that the group selected according to these criteria can represent the research universe with all its qualities (Yıldırım & Şimşek, 2016). The criterion of the study was that the students covered the subject of magnetism. Codes from S1 to S28 were given to the students in the study group to keep their identities confidential.

Data Collection

A semi-structured interview form was used in the study. Within the scope of the magnetism unit, which is taught in the 10th and 11th grades of the high school physics program and covers a large portion of the curriculum, a real life-based problem is given to its students, allowing them to demonstrate their engineering design skills. During the solution process of the problem, students were expected to act as engineers and solve the given real-life problem from the point of view of an engineer. Written forms were used for the 11th-grade high school volunteers participating in the study, in which students described their thoughts, comments, and designs on the solution of the given problem. Although the study was performed in five weeks in total, the study proceeded for two weeks and two hours per week with all 11th-grade students who voluntarily participated in the study. In addition, interviews were conducted with three volunteer students who participated in the study, and the note-taking method was used in this application phase. The research schedule regarding the applications is shown in Table 1.

Table 1

Work Plan

Week	Time Allotted	Implementation
1	1	Creating an explanation video about engineering skills for high school students
2	1	Informing the high school physics teacher at the school where the practice will be performed about the study
3	1	Providing brief information about the engineering profession by using videos and slides
	2	Giving the engineering design problem, discussing the content and context. (e.g., what are they expected to do? etc.)
4	1	Introduction to design studies
	1	Discussion of the difficulties encountered during the design phase and the applicability of the designs.
5	1	Interviews with some students

At the beginning of the study, the students were made an introductory presentation under the heading of "Who is an engineer?" and "What does s/he do?" Following the presentation, the students were given a form prepared by the researchers, including the life-based problem and the related questions, and asked to write their opinions in detail and make their designs. A sample form given to the students is as follows.

The life-based problem: Imagine you are an engineer working in a factory where metal waste is used. A necessary electromagnet system is required for easier collection and separation of metal waste coming to the factory, and you are asked to develop an electromagnet system.

1- What do you think the main problem is in the content of the given problem you are asked to solve? Please, explain it in detail from an engineer's viewpoint.

2- You are required to develop a plan concerning the solution; what are the steps of this plan?

3- What are the (drawings, calculations, etc. belonging to the design of) appropriate solutions for your plan?

4- Will the apparatus which you have designed meet the desired conditions? What do you think about it?

Data Analysis

For the internal validity of the study, the expert examination was used. During the creation of the themes, the findings of the themes were presented to two faculty members who are experts in the field and corrections were made in line with the suggested opinions. In addition, within the scope of the description of the themes, the expressions made by the students in the interviews were exactly stated. To ensure external validity, all stages of the study are clearly stated.

The purpose of content analysis is to collect semantically similar data under codes and themes (Çepni, 2014). To determine the reliability of the research, the answers given to each question asked to high school students were examined, and codes were created. By considering the similarities and differences of the codes, categories were created, and themes were formed from the categories. Direct quotations support themes. After a researcher coded the research data, 25% of the data was evaluated by another researcher according to the code list. The consistency of the codes used by the researchers independently from each other was determined by marking "consensus" or "disagreement". The cases where the researchers used the same code for the students' expressions were accepted as consensus, and the cases where they used different codes were accepted as disagreement. In the sections where there was a contradiction between the researchers, the coding was done by taking expert opinion. Reliability of the data analysis was calculated using the formula of consensus / (agreement + disagreement) x 100 (Miles & Huberman, 1994). The average reliability among coders was calculated to be 92%. With this obtained value, the research is considered reliable.

The data (written documents) collected after these stages were examined by the researchers and evaluated with a content analysis approach

Limitations of the Study

The study is limited to the fact that it was conducted with high school students studying in the 11th grade in a state school in Bursa province, that the students participating in the study did not receive design education, the obtained data were collected with qualitative data tools and the study period was five weeks.

Findings

In the present study, engineering design skills of high school students were examined within the scope of a real life-based problem. The findings were evaluated to understand what is desired in the problem, preliminary design for a solution, mathematical, physical calculations and drawings that follow the preliminary design process including the essence of the design.

When the sets of data belonging to the answers given by the students to the solution of the real life-based problem asked to them were examined, the following findings were found for the first two questions, and they are shown in Table 2 and Table 3.

Table 2

Results of the Analysis of the First Question for the Theme of Understanding the Given Engineering Problem

Theme	Category	Codes	f	%
Understanding the engineering problem	Yield	Save time	6	21
		Gain from material	2	7
		Lower costs	4	14
	Planning	Facilitating the separation of metal waste	7	25
		Vehicle design according to metal size and type	4	14
	Environmental awareness	Recycling	11	39
	Job security	Safe vehicle design	6	21

When the data obtained for the first question of the study were examined, seven codes shown in Table 2 were created. Following the similarities and differences of the codes, four categories were created: yield, planning, environmental awareness, and occupational safety. All categories were analyzed according to the theme of understanding the engineering problem. In the study, 42% of the opinions on high-efficiency category, 39% of the opinions on planning category, 21% of the opinions on occupational safety category and 39% of the opinions focused on the environmental awareness category.

Some sample explanations written by the students concerning the first question are as follows:

S1: It looks like the factory has difficulty in collecting metal wastes and asks us, as an engineer, to develop an electromagnet to collect these wastes. The main problem might be the time. Without an electromagnet, it becomes very difficult to distinguish between metal and non-metal wastes and also it takes a long time to collect them, which decreases daily earnings.

S5: Decreasing the cost by collecting more wastes and using these wastes.

S23: The main problem is to develop an electromagnet to distinguish metal wastes. It is necessary to develop this at a low cost and in a way to obtain the highest efficiency and contribute to recycling. Hence, time is saved via machines instead of human force, as well.

S19: When metal wastes are dropped in nature, they do not disappear for a long time. The matter attracting attention here is environmental pollution. For this reason, it is reasonable to collect metal wastes via an electromagnet to recycle and prevent them from causing damage to nature.

S28: By evaluating metal wastes in the best way, I mean a clean environment and recycling.

Table 3

The Analysis Results of the Second Question Related to the Theme of Planning Steps

Theme	Category	Codes	f	%
Planning steps	Determining conditions	Team building and discussion	6	21
		Factory conditions	7	25
	Designing	Drawing for prototype	17	61
		Determining the materials and cost required for the device to be designed	13	46
	Innovation	To do research and contribute to the purpose of the device to be designed	5	18

When the data obtained from the student responses to the second question are examined, five codes were created, as shown in Table 3. In conformity with the codes' similarities and differences, determining the conditions, designing, and innovation categories were created, and all categories were analyzed according to the planning steps theme. The category of designing in the research is the category with the highest opinion.

Some sample explanations are as follows:

S1: First, I determine the team. Then, I form the plan of the machine and calculate its cost.

S20: The steps of the plan: Firstly, a list that specifies the kind, density, weight and like characteristics of metal substances is formed. Necessary materials, magnets with high attraction force and durable equipment are selected to make a good mechanism by this list.

S21: Firstly, I search into underlying reasons necessitating a solution and prepare a report about these. Based on these reasons, I think of ways to make the most effective solution and compare them with one another and choose the most appropriate.

S23: To develop an electromagnet, which is the most important purpose, I examine high technology electromagnets and then, by starting from these devices, I add extra characteristics, which, in my opinion, are to increase efficiency and decrease cost.

In the third question, the students were expected to use the necessary scientific knowledge and calculations and make the apparatus's drawing plans designed to find the solutions according to the plan. Here, the students are using physics-mathematics knowledge, drawing plans or forming sketches, explanations and originality required for the apparatus to design in accordance with their plans were examined, and the findings are given in Table 4.

Table 4

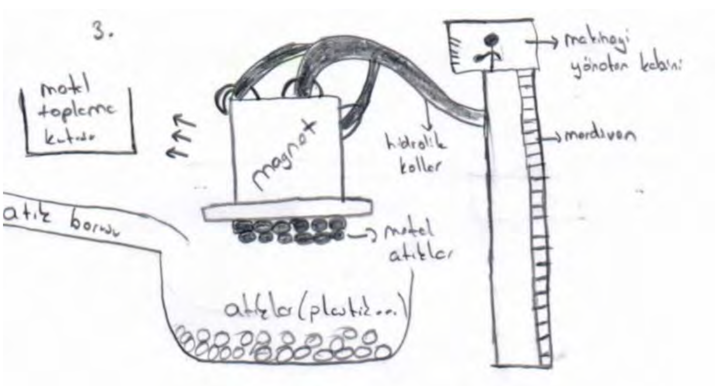
Processes of the Mechanism to Be Designed

Codes	f	%
Using physics-mathematics knowledge	4	14
Creating a drawing plan	27	96
Explain the plan	22	79
Originality	5	18

Some drawings of students' designs selected are given below as an example.

Figure 1

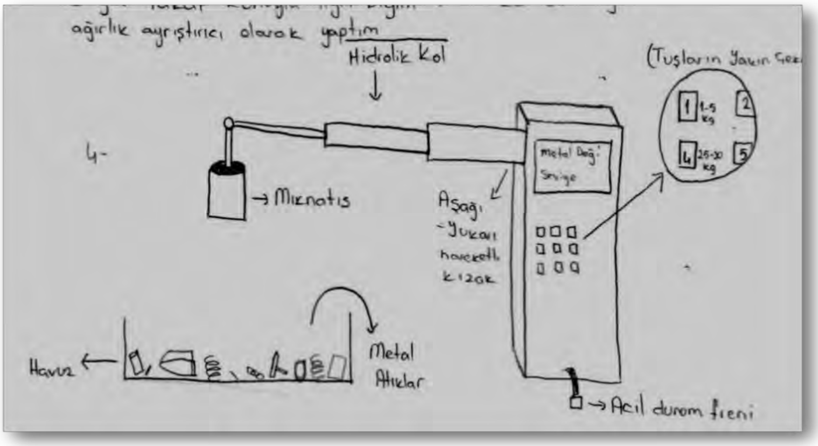
S26's Drawing Plan



S26 made a design which is sending to the metal waste collection warehouse, pulling metal waste from the collection tank with mixed waste with the help of a magnet attached to the hydraulic arm. The student stated a successful plan which is prepared by her/him. Although the design seems beautiful, what is missing here is the lack of scientific knowledge about the electromagnet structure.

Figure 2

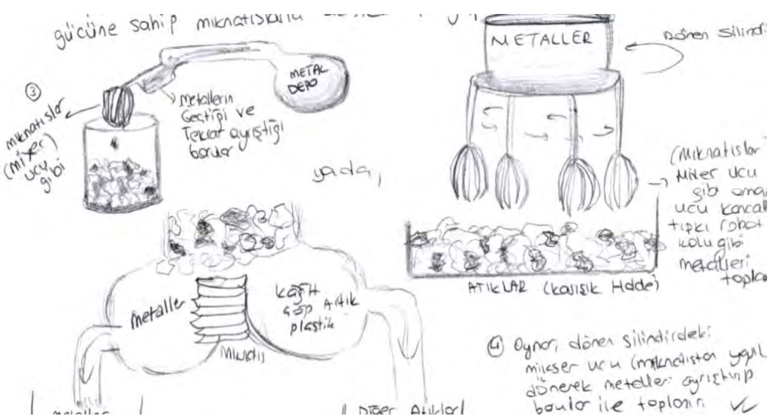
S7's Drawing Plan



In this design, the S7 stated that s/he made a design according to the weights of the metal wastes and put selective buttons on the remote control in the drawing. Again, no scientific knowledge was given about the structure of the electromagnet.

Figure 3

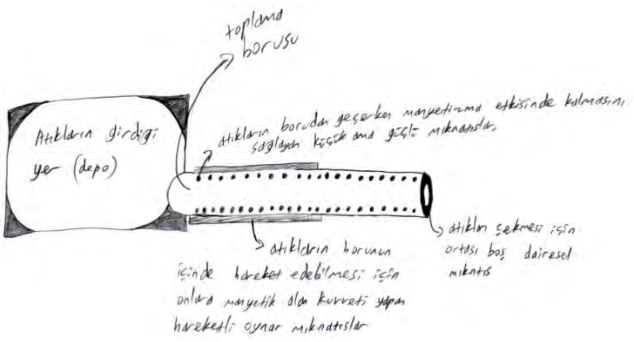
S20's Drawing Plan



Here, the S20 made three designs. In his/her designs, s/he drew magnets in the form of a mixer, inspired by the mixer. S/he stated that s/he could collect metal wastes from mixed wastes in this way, and his/her designs could be supported by magnets with more metal pulling power. As can be seen, there is no explanation for the use of scientific knowledge.

Figure 4

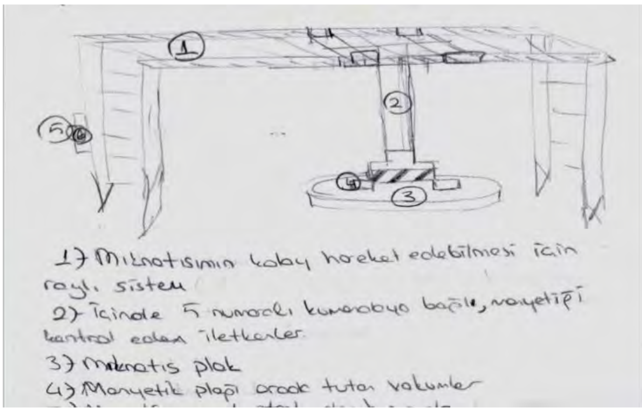
S17's Drawing Plan



The S17 placed small magnets on a cylindrical metal surface. Metal wastes, from mixed wastes sent to cylindrical metal surface, would be attached to the surface with these magnets and then sent to the collection warehouse. While the student was making the drawing, s/he stated an opinion, "I will benefit from the fields of physics and mathematics, but s/he did not give any details".

Figure 5

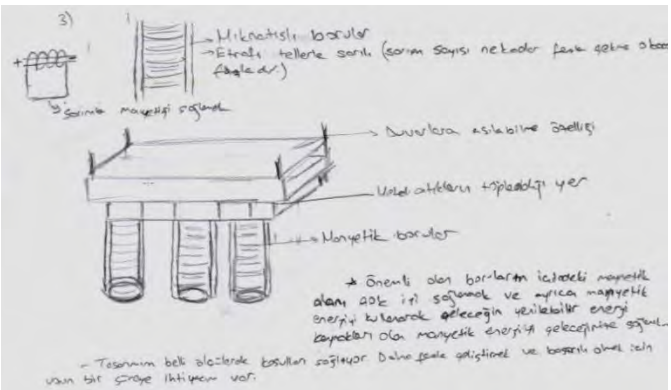
S9's Drawing Plan



The S9 placed electromagnets connected to a mechanism running on a rail system and stated that the attraction of the electromagnet could be controlled via a remote control system. Moreover, s/he stated that the same apparatus could be made with a non-automatic system.

Figure 6

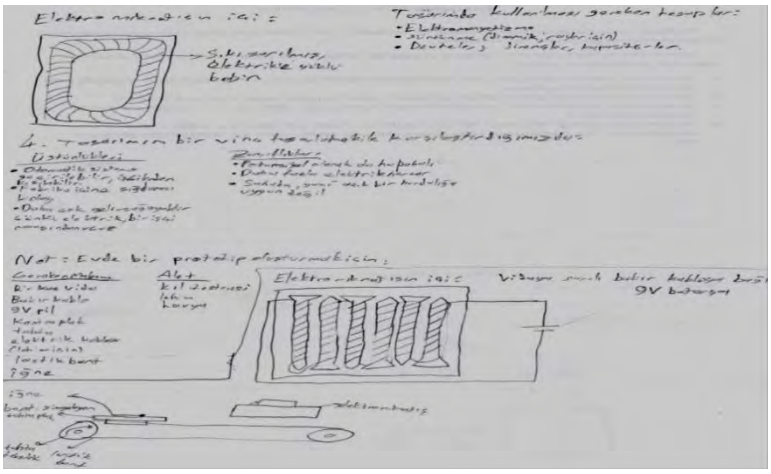
S2's Drawing Plan



In this design, the S2 stated that the wastes that could be hung on the wall and defined as magnetic pipes would be separated and collected in the warehouse above the pipes.
S/he clearly used his/her physics information by stating the relationship between the number of turns of the wire and the attraction force of the electromagnet in the section which s/he described as magnetic pipes.

Figure 7

S6's Drawing Plan



The student made his/her drawing by specifying the weak and strong sides and knowledge and materials in his/her design.

The fourth question directed to the students was "Will the setup you have planned provide the desired conditions? What do you think?". Most of the students stated that their designs would meet the desired conditions. Some examples of students' explanations are as follows:

S14: I trust my design because it will prevent metals from going to waste.

S23: My design will reduce the cost.

S5: The setup that I designed will use metal waste and reduce the cost.

S26: I trust my design and find it successful.

Some students used more careful expressions. For example:

S2: My design satisfies certain conditions. I need a long time to develop and be successful.

S6, on the other hand, made an explanation about the strengths and weaknesses of the planned setup. S/he stated the superior sides as saving on the number of workers by switching to an automatic system, fitting into the factory, increasing incomes due to the savings in the number of workers, and the weaknesses as high cost and not suitable for open scrap yards.

Discussion and Interpretation

The students perceived and stated the real-life problem which was asked to solve and its different dimensions in the engineering problem. Real-life problems require students to think mathematically to find an algorithm different from what is learned in the classroom. And this is based on analyzing the problem better. Moreover, it is also important to ask the right questions and think critically.

At this stage, what is expected from the students is to determine the problem included within the real-life problem given to them, put forward the scope with their statements and emphasize the necessity of developing a new electromagnet. When the students' answers were examined, it was observed that they also considered some important factors such as problems and solutions in the electromagnet development process, determining time and material for a factory oriented toward production, low cost, work easiness and safety (Table 2). Moreover, in the study, it was also observed that 39% of the students highlighted environmental awareness, which was indirectly related to the problem. Since the problem was related to metal wastes, this might have led to the appearance of thought of this kind. For example, as seen in the students' statements numbered S19 and S28, the relationship between the concept of waste and environmental pollution rises to prominence.

Determining the necessary equipment and cost and making a drawing for a prototype for a device to be designed was the most emphasized category. However, the importance of the existing conditions and searching was less emphasized.

In the second question, the skill of putting forward a solution to a determined problem and forming this solution within the framework of a plan was expected from the students. In order to put forward a solution, it is necessary to have a creativity allowing for thinking of new suggestions and the necessary equipment and tools, consider cost and conditions and make design by taking these into account. As it is seen in Table 3, the students stated opinions mentioning these conditions.

Determining the necessary equipment and cost and making a drawing for a prototype for a device to be designed was the mostly emphasized category. However, the importance of the existing conditions and searching was less emphasized. Another result seen in Table 3 was the students' having suggested a solution based on innovation. Haik and Shahin (2012) expressed that a device or a system could be designed in two important ways. 18% of the participant students suggested a solution based on innovation, which results from technological discoveries. As it is known, creative skills and analytical ability play an important role in innovation.

In the third question, to realize the solutions under the plan, the students were expected to use the necessary scientific knowledge, make the required calculations and draw plans for the device to be designed. When the study data was examined, a high level of participation was observed in making drawing plans and explanations. When the drawing plans were examined, it was observed that although the students exhibited their creativity, the practicability levels of these plans were low, and they were far from details.

There are also some examples reflecting creativity in designs made by students (examples S20 and S17). However, this kind of example is few in number. It is understood from their draft drawings that the students were generally affected by the device models they saw around them. However, while individuals present their possible solution suggestions, they must use their creativity (Mentzer, 2011). Moreover, when it was examined in terms of design, variety, development and new design type which are mentioned by Haik and Shahin (2012) were not encountered. It was observed that the designs were generally adaptable.

When the drawings of students' designs are examined based on scientifically correct and applicable, scientifically correct but not applicable themes, it can be said that the drawings of students numbered S26, S7, S20 and S9 are scientifically correct and applicable, on the other hand, the drawings of students numbered S17 and S2 are scientifically correct but inapplicable.

In addition, when drawings of students' designs are examined based on the design output classifications of Gero and Kannengiesser (2004), it is seen that designs can be evaluated as applicable designs.

When it was looked at from the perspective of the cyclical steps of the design process, it was observed that most of the students did not take the next step of forming a prototype into account at this stage. When this situation is discussed with the students, they stated that they actually wanted to make prototypes. However, they stated that they could not spare time for reasons such as cost, the intensity of the lessons and exams. Çiftçi and Topçu (2020) stated in their research that developing prototypes, generating ideas, and testing were the stages that students both had the most difficulty and liked the most. However, Hynes et al. (2011) described the formation of a prototype as the only concept which the students had about engineering before taking any engineering design education.

Another finding was that using scientific knowledge and making calculations were not realized at an expected ratio. Only 10% of the students mentioned the number of turns and the relationship between current and magnetic force as scientific knowledge. When it is considered that the students studied this subject in the 10th grade, they were especially expected to use this knowledge. It is necessary to include scientific knowledge to develop the skills required in the engineering design process. This result is in line with Mentzer, Huffman and Thayer's (2014) studies with 20 high school students. The researchers concluded that most of the 20 students did not explain their design decisions via mathematical relationships or functions. Again, it is also in line with the results of the study made by Berland, Steingut and Ko (2014) with the high school students. Berland, Steingut and Ko (2014) suggested that "we should develop a curriculum that includes engineering design challenges in which students could not succeed without engaging with the quantitative - with mathematics and science". Vaino, Vaino and Ottander (2018) stated that one of the results they reached in their study on ice cream machine design with 24 eighth grade students was the difficulty experienced in accessing information about the subject, and the other transferring or using the relevant information to the design process.

Schunn (2011) stated that to have a rich design experience where students establish deep connections between science and design, they should focus on the relevant target concepts as much as the time spent on design difficulty. For example, he stated that since students need to learn important big ideas in chemistry regardless of the system they want to design, they might be asked to design chemical-based heating or cooling systems to teach basic thermodynamic concepts in a chemistry lesson.

In addition, Hynes et al. (2011) stated that it is necessary to see the learning purpose of engineering design as a practical application of mathematics and science and encourage students to learn with engineering design. Moreover, the success of the design is related to the correct and proper use of the necessary scientific information about the design. As Vaino, Vaino and Ottander (2018) pointed out the lack of scientific knowledge leads to unrealistic designs. Similarly, unrealistic drawings were also found in our study.

Suggestions

High school students should be given opportunities to exhibit their ability to determine a need or a problem in a certain case. Problems covering engineering design processes, which are likely to be encountered in real life, can be transferred into the classroom environment, and students can be expected to offer solution suggestions. In the 21st century, design is regarded as an important component of engineering-based problem-solving skills and the necessity of students' doing more practices to design drawings is emphasized. At the same time, engineering design serves students to use all science and mathematics knowledge and materials as they learn during their education (Hynes et al., 2011). Suppose the idea stated by Fan and Yu (2017) that "The engineering design approach at high school level develops the integration of knowledge related to such fields as science, technology, engineering and mathematics" is taken into consideration. In that case, it can be stated that the engineering design approach can form an ideal beginning to include engineering practices into the existing secondary education curriculum. Today, the engineering design process should be considered as a basic part of science education. It is suggested that engineering design approach be used in our country, too, as a useful educational strategy in science programs.

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