ENGINEERING DESIGN-BASED ACTIVITY FOR MIDDLE SCHOOL STUDENTS: THERMAL INSULATION[1]

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ABSTRACT

The aim of this study is to present the implementation steps of an engineering design process-based activity. The activity was implemented with 6th-grade students; 21 students were involved. Various visuals were used to attract the students' attention during the introduction of the activity, and discussions were held about engineers and engineering. In the design process, students were asked to design a thermos that meets the criteria and limitations of the problem by following the eight-step engineering design process. The students researched the problem through information cards, suggested different solutions, and chose the one that solved the problem best among the alternatives. The activity continued with constructing and testing the thermos, sharing solutions, and determining the thermos design with the least temperature change. The students were asked to make suggestions to improve their thermos designs. The activity was evaluated by using the diagnostic tree, analytical rubric, and Draw an Engineer Test.
Keywords: engineering design process, STEM education, thermal insulation, middle school students.

ORTAOKUL ÖĞRENCİLERİ İÇİN MÜHENDİSLİK TASARIM SÜRECİNE DAYALI BİR ETKİNLİK: ISI YALITIMI

ÖZ

Bu çalışmanın amacı mühendislik tasarım sürecine dayalı olarak hazırlanan bir etkinliğin uygulama basamaklarını tanıtmaktır. Bu etkinlik 6. sınıf öğrencileri ile uygulanmış ve uygulamaya 21 öğrenci katılmıştır. Etkinliğe giriş aşamasında öğrencilerin dikkatini çekmek amacıyla çeşitli görseller kullanılmış, mühendis ve mühendislik ile ilgili tartışmalar yapılmıştır. Daha sonra öğrencilerden sekiz basamaklı mühendislik tasarım sürecini takip ederek problemdeki kriter ve sınırlılıkları karşılayan bir termos tasarımı yapmaları istenmiştir. Öğrenciler öncelikle problemi belirlemiş ve problemle ilgili bilgi kartlarını kullanarak araştırma yapmışlardır. Daha sonra farklı çözüm yolları üretmiş ve alternatif çözümler arasından problemi en iyi çözeni seçmişlerdir. Seçilen çözüm için verilen malzemeleri kullanarak termos tasarımlarını oluşturmuş ve test etmişlerdir. Test etme sürecinin sonunda öğrenciler tasarımlarını sınıfla paylaşmış ve sıcaklık değişimi en az olan termos tasarımını belirlemişlerdir. Son aşamada öğrencilerden termos tasarımlarını iyileştirmek için önerilerde bulunmaları istenmiştir. Etkinliğin değerlendirilmesi için tanılayıcı dallanmış ağaç, analitik rubrik ve Bir Mühendis Çizelim Testi kullanılmıştır.
Anahtar kelimeler: mühendislik tasarım süreci, STEM eğitimi, ısı yalıtımı, ortaokul öğrencileri.

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INTRODUCTION

There is much ambiguity regarding how to integrate Science, Technology, Engineering, and Mathematics (STEM) disciplines (Martin-Paez et al., 2019), and the engineering design process is considered a fruitful way to bring different STEM disciplines together (Kelley & Knowles, 2016). The engineering design process is described as an "iterative process that begins with the identification of a problem and ends with a solution that takes into account the identified constraints and meets specifications for desired performance" (The National Academy of Engineering [NAE], 2010, pp. 6-7). Engaging in the engineering design process helps learners to solve engineering-related problems by utilizing science and mathematics concepts (Bryan & Guzey, 2020; Moore et al., 2014), learning from their mistakes (Cunningham & Carlsen, 2014; Maiorca & Mohr-Schroeder, 2020), working collaboratively (Fan et al., 2021), communicating the solutions (Bryan et al., 2015) and augmenting their 21st-century skills such as critical thinking and creativity (Wendell et al., 2017). Moreover, presenting authentic, real-life-based problems and finding solutions to them through the engineering design process allows active student participation and enhances their learning (Roehrig et al., 2012). In line with the international attempts to incorporate practices of science and engineering into Standards (Next Generation Science Standards [NGSS], 2013), the latest developed science curriculum in Turkey promotes students' understanding of engineering and engineering practices in addition to scientific practices (Ministry of National Education [MoNE], 2013).

The activity about designing thermos was prepared in the context of lesson study, which is one type of professional development program. Lesson study is iterative in nature and mainly includes planning, implementing, and reflecting phases (Lewis et al., 2006). Four preservice science teachers designed the lesson plan collaboratively and worked with mentors (the authors of the paper) from the faculty of education during this lesson study. The study aims to support the development of preservice science teachers' pedagogical content knowledge for STEM through lesson study (Juhler, 2016). First, the engineering and engineering design process was introduced to the preservice science teachers. Second, a collaborative lesson plan was prepared as a group with the presence of a mentor in the planning phase. In the teaching phase, one of the preservice science teachers implemented the lesson plan in the sixth grade (11-year-old students) classroom in 4 lesson hours (4x40 minutes) while other preservice science teachers and one mentor observed the lesson and took notes. Third, the group met to revise the lesson plan based on their observations in the reflecting phase. The mentors guided the discussions on how to use knowledge of thermal insulation in the design process, identify and remediate students' misconceptions in science and engineering and assess the objectives of the lesson while reflecting on the lesson. Fourth, some modifications were done on the lesson plan as a group. The lesson plan was finalized and implemented in another sixth-grade classroom by another preservice science teacher in the group, and the mentor observed the teaching part. Finally, the group met again and improved the lesson plan. We presented the revised version of the lesson plan based on the engineering design process after two implementations in the present study. This activity was implemented as a part of a doctoral dissertation, and necessary ethical approval was taken.

In the literature, at the middle school level thermal insulation topic was covered through different activities. For instance, Aymen-Peker et al. (2012) utilized argumentation to prepare an activity regarding thermal insulation. The students worked in groups, created the model of houses by choosing one thermal insulator material, and followed Toulmin's (1958) argumentation pattern to justify their reasons for the choice of insulator material. Similarly, Yaman (2018) investigated the influence of the science writing heuristic approach on sixth-grade students' understanding of heat and matter topics. Experimental group conducted activities based on argumentation, whereas the control group was subjected to regular instruction. In one of the activities in the experimental group, students were required to write a letter to their peers about thermal insulator materials used in buildings after completing the argumentation-based activities. The other activity used scenario-supported project-based learning to promote students' understanding of thermal insulation (Denis-Celiker et al., 2014). Students were given seven scenarios about heat conductors, insulators, thermal insulation materials, and heat convection. One of the scenarios asked for forming building models that keep the house warmer. Students were expected to explain what kind of materials could be used in their model.

Moreover, some studies prepared activities based on the STEM education approach. Sirin and Celikkiran (2021) created entrepreneurship-based STEM activities, and one of the activities was related to thermos design. The authors did not follow any engineering design process models in the activity, and the primary purpose of the study was to improve students' entrepreneurship skills. Similarly, Kahraman and Cetin (2020) investigated the effect of STEM activities prepared based on several science topics on eighth-grade students' motivation to learn science. One of the activities was about thermal insulation. Additionally, some studies utilized the engineering design process to make students comprehend the thermal insulation concept. For instance, Uzel and Canbazoglu-Bilici (2022) developed five engineering design-based activities based on Hynes et al. (2011) model and examined their effects on sixth-grade students' problem-solving skills. Designing thermometers, anti-freezing milk tanks, and houses were examples of activities developed within this scope. Akaygun and Aslan-Tutak (2016) created a thermos activity for fifth-grade students. The students were provided with a knowledge-based life problem and designed thermoses by considering predetermined criteria and limitations. Some materials, such as cotton, aluminum foil, and paper towels, were given to the students, and they chose materials among these alternatives. They tested their designs and selected the most efficient thermos. Then, all groups were asked to produce the most efficient thermos chosen from the previous phase of the lesson.

The present study followed the engineering design process model by the Massachusetts Department of Education (2006). The eight steps of the engineering design process are given below:

1. **Identify the problem:** Students are expected to identify the problem and write the criteria/limitations of the problem.
2. **Research the problem:** Background knowledge to solve the problem is obtained.
3. **Develop possible solutions:** Alternative ideas for design solutions are discussed.
4. **Select the best solution:** The alternative solutions are weighted, and the one that solves the problem better is selected.
5. **Construct a prototype:** Two or three-dimensional prototypes are created.
6. **Test and evaluate the solution:** The data are collected, and "Does the prototype work? Does it meet the original design limitations?" questions are tried to be answered (Massachusetts Department of Education, 2006, p. 84).
7. **Communicate the solution:** The findings are presented in several ways (i.e., poster, video, etc.)
8. **Re-design:** Students troubleshoot their designs.

This engineering design process is used in this study to develop an activity emphasizing that students should provide more than two possible solutions to the given problem and consider the alternative points of view, which contributes to developing their critical thinking and creativity skills (Crismond & Adams, 2012). They should decide upon the best solution. While doing this, students should consider the trade-offs and strengths of their solutions. This is one of the essential aspects of the current activity. Moreover, the engineering notebook is integrated into the thermal insulation activity in accordance with the engineering design process model, and it is one of the most significant parts of the activity. The engineering notebook supports students in terms of organizing the steps of the engineering design process and engaging them in engineering practices (Hertel et al., 2017). Therefore, an engineering notebook (Appendix 1) is utilized in the present study to attain these goals. Students are provided with an opportunity to record their collaborative work while solving the engineering problem and review the steps they complete. In this way, the engineering notebook supports the development of evidence-based decision-making skills. Moreover, the engineering notebook is enriched with decision diagrams. Decision diagrams enable "weighting options and making decisions" (Crismond & Adams, 2012, p. 761). For instance, students are required to fill out a decision diagram while deciding on the best solution among the alternatives, and they need to consider the criteria and limitations at this point. The decision table facilitates the decision-making process and allows students to discuss science concepts in the context of the engineering design process. Besides, it is pointed out that "engineering talk" can be utilized to integrate engineering explicitly (Guzey et al., 2019, p. 25). Infusing discipline-specific talk as a part of a lesson, such as constraints, client, design, learning from failure, etc., creates an opportunity to apply engineering concepts. The present study benefits from engineering-related visuals and explicitly addresses the related terms throughout the lesson. Employing engineering language in the lesson is considered helpful to comprehend the nature of the engineering design process (Guzey et al., 2019) and is highlighted in this activity.

Different from the other thermal insulation activities mentioned above, students need to design thermoses by considering the body and outside of the thermos in the present activity. They choose between glass, plastic cups, styrofoam cups, and cartoon cups for the interior part. For the exterior part, they have several alternatives including cotton, cartoon, glass wool, fabric, felt, and bubble wrap. Therefore, students should consider various characteristics of thermal insulation materials and are asked to determine which combinations of thermal insulators worked well instead of focusing on the properties of one thermal insulator material. Another aspect of the activity focuses on science-related misconceptions about thermal insulation, such as insulators are the source of heat; cold is transferred between objects (The Ohio State University, n.d.), and engineering-related misconceptions. Students might have misconceptions, such as "there is only one correct solution to the engineering problem, the engineering design process is linear, generating only one solution to the problem is enough" (Crismond & Adams, 2012), engineers are builders, they work alone, and they are male (Fralick et al., 2009). These misconceptions are attempted to minimize while planning and implementing the activity in this study.

The big idea of the lesson was thermal insulation, and students followed the engineering design process steps to learn this concept in the present study. The "Designing a Thermos" activity was prepared by considering the objectives of the science curriculum (MoNE, 2018a), technology and design curriculum (MoNE, 2018b), and mathematics curriculum (MoNE, 2018c). Related objectives from these curricula were examined and then adapted for this activity. For instance, "F.6.4.3.2. determine the selection criteria of thermal insulation materials used in buildings" (MoNE, 2018a, p. 35) objective was taken from the science curriculum in the sixth grade and used in this study by excluding the "building" part. The engineering objectives were determined by considering the steps of the engineering design process, the engineering practices provided in the science curriculum (MoNE, 2018a, p. 10), and objectives in Technology and Design Curriculum, such as "TT.8.C.3.4. design a product using the engineering design process" (MoNE, 2018b, p. 22). The mathematics objective of the activity was adapted from "M.4.4.1.4. solve daily-life problems using the information shown in column graphs, tables and other graphs" (MoNE, 2018c, p. 50). Moreover, the activity aligned with the purposes of the science curriculum in terms of promoting career awareness (MoNE, 2018a, p. 9). The learning objectives of the activity are as follows:

- Determine the selection criteria for thermal insulation materials.
- Use the engineering design process to build a prototype that minimizes thermal energy transfer.
- Explain how engineers design solutions to problems.
- Collect the data on how the recommended solution to the engineering problem works and fill the table according to the data obtained.
- Increase awareness of engineering-related careers.

ACTIVITY IMPLEMENTATION

At the beginning of the lesson, the teacher asks questions to the whole classroom to get their attention to the activity, such as: "Who is an engineer? What does an engineer do?". The visuals named "The World Without Engineers" are shown to the students to gain their interest in the lesson. One of the visuals is given in Figure 1. The students were encouraged to share their ideas about what would happen if engineers did not exist and make comments about how engineers develop solutions to daily-life problems. The excerpt below is taken from the classroom:

> Teacher: What do you see in the first visual? (Figure 1)
> S1: There is something like a laptop.
> Teacher: Yes, they are measuring something.
> S2: Like a calculator.
> S3: It is like an old, undeveloped version of the computer.
> Teacher: Exactly. Calculators would be this big without engineers, so many people would work to calculate, as you see in this visual.
> S4: Even mobile phones have calculators now.
> Teacher: You are right. The problem was that calculators were too big, and engineers solved it. They designed smaller calculators and put them as an application on our mobile phones, as you have said.

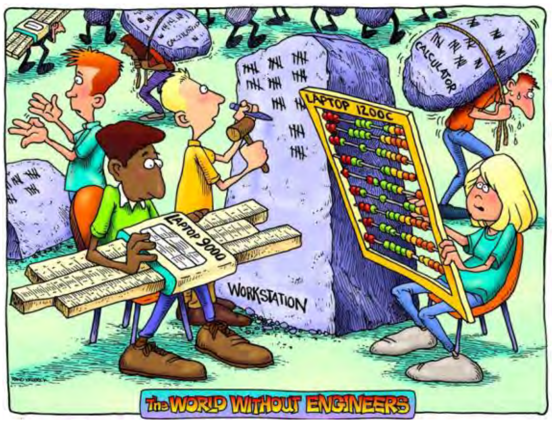


Figure 1. "The World without Engineers" (n.d).

Moreover, as the discussions about these visuals progress, a common misconception about the work of engineers may arise. The following dialogue indicates how the teacher dealt with the engineering-related misconception:

> S1: I think scientists and engineers are the same people; they are doing the same thing.
> Teacher: Why do you think so?
> S2: No, I don't agree. I think engineers design something and create things.
> Teacher: Yes, you are right. Let me explain this way (he wrote the d=m/v formula on the board). Scientists work on these types of formulas. They study the relationship between concepts, for example, how density changes with the increase in volume. On the other hand, engineers use these principles to design; for instance, they design ships.

Afterward, the teacher explained that they will solve an engineering problem about thermal insulation in the following lessons. Before continuing the activity, some questions were asked to understand students' prior knowledge about the topic. For instance:

> Teacher: I have two solids in my hand. One of them is a conductor, and one of them is an insulator. Where does this difference originate?
> S1: Insulators have regular particles, but conductors have discrete particles.

Then, the "Engineering Design Process" poster was shared with the students, and the teacher explained the steps they will follow as an engineer in the next lessons (Figure 2). The poster was posted on the board so that the students could access it whenever needed. There were 21 students in the classroom on the day of implementation, and they were divided into four groups. This introduction part took approximately 20 minutes.

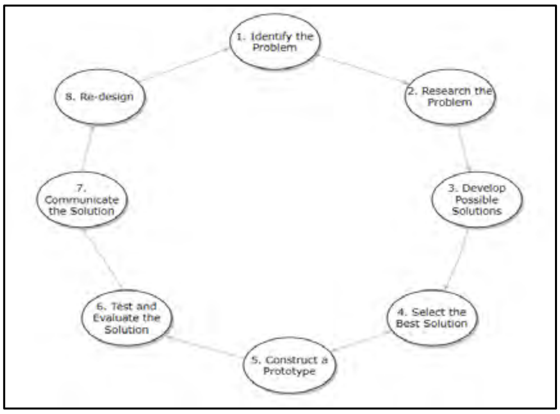


Figure 2. The Steps of the Engineering Design Process

The materials list:

- The materials for the body of the thermos: glass cups, plastic cups, styrofoam cups, and cartoon cups.
- The materials for thermal insulation: cotton, aluminum foil, fiberglass wool, wool fabric, fibre, cling film, sponge, felt, and bubble wrap nylon.

Identify the Problem

This phase took about 10 minutes. The

engineering design challenge was presented to the classroom through an animated video prepared in Vyond software. Students took the role of engineers and were asked to design thermos to keep the soup hot inside. The client says: "Young engineers, I need you to find a solution to my problem. The thermos should contain at least two insulation materials, have a lid, be easy to carry, durable and keep the soup hot for at least 25 minutes. It should not exceed the budget of 30 TL and should be ready in one week" at the end of the animated video. After introducing the problem, student groups discussed and defined the problem and listed the criteria and limitations of the design challenge in the engineering notebook. Students might be confused about the difference between defining criteria and limitations at this point. An example dialogue is provided below while discussing the criteria and limitations of the problem:

> Teacher: (while walking around the groups) What are the limitations of our engineering design problem?
> S1: The thermos design should be durable.
> Teacher: The limitation is something that limits us in the design process. Remember the example that I provided at the beginning of the lesson. 64 GB memory and black are the features that I want to buy a telephone. I have 5.000 TL to buy a cell phone, and this budget limits me. Although I want to buy a cell phone with 64 GB memory, I have to buy 32 GB. I have to compromise on the feature I want. If we think about our problem, is it a criterion or a limitation to want it to be durable?
> S1: Then, it is the criteria because I want a durable thermos.

Research the Problem

This phase took about 20 minutes. It is expected to search for the problem using the internet, books, journals, etc. (Aydin-Gunbatar, 2018). Information cards could be used as one alternative when there are no computers or the internet and were prepared for the purpose of this study (for cotton, aluminum foil, glass wool, etc.) (Appendix 2). They contained basic information about the materials, such as their strength, lifetime, cost, water absorption, and effect on human health. The groups were expected to examine these cards and discuss the characteristics of thermal insulation materials. They were expected to fill out a table in the engineering notebook regarding the characteristics of good thermal insulator materials. For instance, one group wrote about the characteristics of good thermal insulators: "It should not burn easily and should not be heavy. It should be long-lasting and have low thermal conductivity".

Develop Possible Solutions

This phase took about 20 minutes. Students were asked to develop at least two solutions to the given challenge in their small group work. Every student in the group was encouraged to offer one solution individually. However, some groups might have difficulty producing more than one solution and might consider just generating a single solution enough. In this activity, the teacher noticed and tried to eliminate this misconception, as provided in the excerpt below:

> Teacher: (while walking around the groups) Why do you write only one solution?
> S1: We do not have an alternative idea. Our solution will solve the problem.
> S2: We cannot find another solution.
> Teacher: Let's look at the possible materials and their prices. Let's discuss this again. What if we use foam instead of glass in the body of the thermos? What other combination could we do?
> S1: Our budget will decrease if we use foam… On the other hand, it has lower thermal conductivity.
> Teacher: Very good. We should think about these alternative points while writing the second solution.

The students must decide what material the thermos body will be made of. The alternatives were glass, plastic, styrofoam, and cartoon cups. The heat insulator materials, which were cotton, aluminum foil, cartoon, fiberglass wool, sponge, fabric, felt, and bubble wrap, were given to the students. The students were expected to use the information cards and their prior knowledge/experiences to solve the engineering design problem.

Select the Best Solution

This phase took about 15 minutes. In this part, the students needed to choose the best solution among the alternatives they had generated. The decision diagram helped make their decision in this part of the engineering notebook. The students were expected to consider different points of view; for example, they might want to use fiberglass wool because of its low thermal conductivity, but fiberglass wool is harmful to people when direct contact is made. The students needed to use other supportive materials, which increased the budget. Therefore, they were expected to decide which part of the design to compromise. The following dialogue indicates how students compromised the budget:

> Teacher: Why did you want to use glass wool in your design? (Referring to the best solution among alternatives while walking around the groups).
> S1: Because it is thick and warm, lower thermal conductivity.
> Teacher: Why will you cover it with aluminum foil?
> S1: For easy transport and glass wool is harmful to human health. Therefore, we have to use it.
> Teacher: Have you considered your budget? You know that designing thermos with the lowest budget is also important.
> S1: Yes, the budget is increased but still under 30TL. We believe this design will keep the soup hotter than our other options.

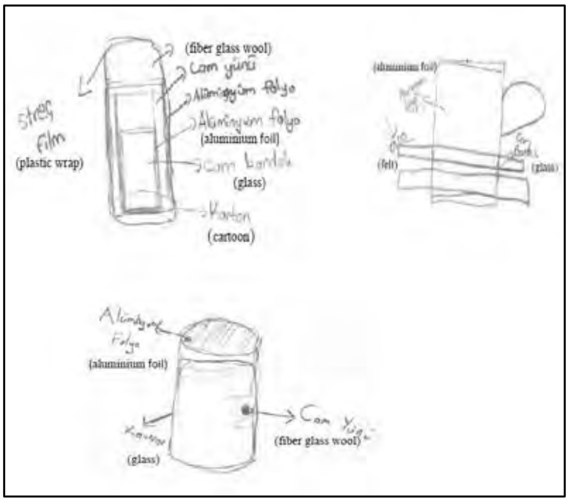
Group 2 focused on the criteria of being durable while choosing the interior part of the thermos as follows:

> S1: We can choose a styrofoam cup but it is not durable very much. On the other hand, when I buy tea from the canteen with a paper cup, it gets wet.
> S2: I think we should choose a glass cup. It is durable and does not leak any liquid.

The students decided the best solution to solve the engineering design problem. Then, they filled out a decision table to determine to what extent their design met the criteria and limitations in the engineering notebook. Example quotes from the present study are as follows: One group indicated that "we decided to continue with our second solution because the first one could not meet the criteria of being waterproof although we chose the material with low thermal conductivity," while the other group expressed that "we chose the first alternative because it is more cost-effective and easier to carry."

Construct a Prototype

This phase took about 20 minutes. The students drew the diagram of their designs in the engineering notebook. They need to write and label the materials they will use for their design on the prototype drawings. Some examples from the students' drawings obtained in this study are presented in Photograph 1. The final budget should be calculated and written into the engineering notebook. Later, students should take the necessary materials from the teacher and construct their designs as a group to be tested.



Photograph 1. Examples from Students' Drawings

Test and Evaluate the Solution

This phase took about 30 minutes. All groups brought their designs to share with the classroom. To test their designs, the teacher used a kettle to heat water. Every group should have one "data analyst" to collect and record data. The teacher drew a data table with the groups' names on the board. While testing the designs, the data analysts should record their groups' data in this table. In this way, the students are provided with the opportunity to compare their data and evaluate the effectiveness of their design solutions with other groups. To test the designs, the teacher poured 150 ml. hot water (approximately 60^0 C) into the thermoses because of safety issues. The measures were taken at the same time by using thermometers. The data collection was repeated every five minutes. Five measures were taken during the testing period, and the difference between the last and first measures was calculated and written in the engineering notebook. The thermos designs with the greatest and least difference in temperature were determined. Examples of students' designs created in this study are given in Photograph 2.

Photograph 2. Some Examples of Students' Designs of Thermos

Communicate the Solution

This phase took about 15 minutes. One student from each group explained which materials they preferred to choose as a body and insulator(s) and gave a scientific justification for their decisions. The budget for the design was also mentioned. Discussions about which combination of thermal insulators was more effective and which design solutions have met the criteria and limitations set at the beginning of the lesson were guided by the teacher. Some misconceptions regarding the engineering design process might emerge, such as there is only one correct solution to the problem. An instance when one of the students presents their design in this activity is given below:

S1: We were the group with the highest temperature change (in our thermos design). Why did our design fail?

Teacher: There is no single successful design to deliver a solution to the engineering problem. You may not have chosen the appropriate combination of thermal insulator materials. Let's listen to other groups' solutions. I will write down every group's combination of thermal insulators next to the table (data collection table that shows groups' temperature changes). Then, we might discuss the points that might be improved in your thermos design in the re-design part of the engineering notebook.

Re-design

This phase took about 15 minutes. The students were asked to reconsider their design after listening to other groups' solutions to the engineering design problem. Then, they conceptually re-designed their prototypes in their groups. It is recommended that students re-build and re-test their design if the time limit is not a problem (approximately two extra lesson hours are required). The rationale for the proposed changes should be explained in the engineering notebook. The re-design part of the engineering notebook includes determining the designs' strengths and weaknesses and the points that need improvement. The teacher should ask some guiding questions as follows to encourage students at this step:

Teacher: What would you change if you made this thermos design again?

S1: Nothing.

Teacher: Is there anything that should be improved in your design? Can you make changes in choosing the materials? Is there a problem with the lid? Has the thermometer been placed so it can take a correct measurement without losing heat?

Moreover, an example from the students' ideas of improvement of their designs written in the engineering notebook is given below:

Group 1: We think we need to change the thermos lid. We believe most heat escaped from the lid because we only used aluminum foil. We should use fiberglass wool in the lid and cover it with felt since just using it in the lid could harm our health. (Improvement in the design).

Another example for determining the weaknesses of designs from the engineering notebook is given as follows:

Group 4: The lid of the thermos could close better; we can further reduce the heat exchange between the inside and outside of the thermos (a weakness of the design).

Assessment of the Lesson

This phase took about 15 minutes. The diagnostic tree was implemented as a small group activity to uncover students' conceptual knowledge of thermal insulation in the current activity. It was enriched with probable misconceptions about thermal insulation. The sample items are: "Thermal insulation reduces the heat exchange between environments, thermal insulators have higher thermal conductivity," etc. The diagnostic tree with seven statements is shown in Appendix 3. Each correct item is scored as one point, and the groups who answer all items correctly get three points. Two groups got three points on the diagnostic tree, while two got two points and chose the wrong answer regarding thermal conductivity in this activity. During implementation, the small groups were given 5 minutes to find the correct exit in the diagnostic tree and the teacher distributed the assessment sheet. Then, the teacher collected them after 5 minutes, and the whole classroom discussion was held using the smart board. The teacher directed questions to the groups and asked them to comment on every item in the diagnostic tree. The following dialogues are taken from the whole class discussion:

> Teacher: Let's look at this statement (showing from the smart board). It says that thermal insulators have higher thermal conductivity. What do you think about this statement?
> S1: I think it is correct.
> Teacher: Why do you think so?
> S: (no response).
> Teacher: Remember the thermos you have created; the most successful design was the one with the least temperature difference. They used fiberglass wool as the primary material. Its' thermal conductivity was low, as we learned from the information cards.

The teacher provided feedback about the wrong answer, and she addressed the engineering design process to support the learners. All items in the diagnostic tree were covered through classroom discussion, and the teacher explained the missing parts.

Moreover, the analytic rubric was prepared for assessing the steps of the engineering notebook (Appendix 4). In this way, the groups' performances were evaluated based on several criteria. The rubric was used after implementing the activity in the reflection meeting. The steps of the engineering design process were placed in the rubric, and students' responses were scored on a three-point scale. For instance, if students were able to determine the best solution by addressing the criteria and limitations, they got two points on a predetermined criterion. If the best solution was determined without addressing the criteria or limitations, they got one point, and if they did not specify both of them, they could not earn points on this criterion. After assessing the engineering notebooks, the teacher used the assessment results to revise the instruction. For example, two out of four groups got lower grades in the re-designing part of this activity. The teacher devoted more time to re-designing part and emphasized the importance of determining design solutions' weaknesses and strengths while using the engineering design process in the next activity.

Lastly, the students were given homework for the next lesson. "Draw-an-Engineer-Test (DAET) (see Appendix 5) was used to understand students' perceptions of engineers (Knight & Cunningham, 2004) in this study since one of the purposes of the activity was to introduce engineering careers. On the front page of the test, students are asked to imagine an engineer at work and draw it. On the next page, they should describe the characteristics of engineers and their work environments. The checklist developed by Fralick et al. (2009) was used to assess the DAET (Appendix 6). When the drawings were analyzed, it was seen that most of the students (72%) had accurate perceptions of engineers' work. Nearly half of the participants (52%) imagined engineers as women characters contrary to Fralick et al. (2009)'s study. Moreover, the majority of the students considered (67%) engineers as designers and problem solvers. For instance, Student 17 explained that "the engineer in the drawing writes codes for the computer program" (Figure 3), whereas Student 6 indicated that "I drew an agricultural engineer, and she is developing chemical products that do not harm flowers and make them grow faster." The students underlined how engineers solve problems and make everyday life easier. For instance, Figure 4 demonstrates that Student 11 imagined an engineer as designing an earthquake-resistant school. Few students thought engineers were fixers and builders in the DAET after attending the engineering design-based activity. Another significant finding is related to the number of other people in the drawings. Nearly all students drew engineers working alone. Therefore, the teacher utilized the results of this test to emphasize the importance of group work while engineers solve problems in the following engineering design-based activities. In brief, students' engineering related-misconceptions were determined and addressed through DAET in this activity.

Figure 3. Example-1 from Student Drawings in DAET

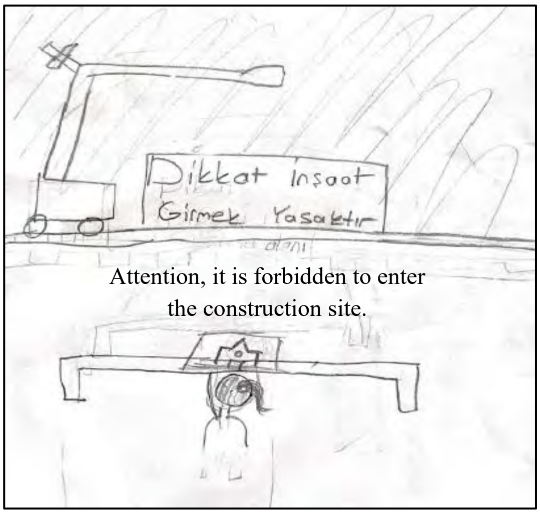


Figure 4. Example-2 from Student Drawings in DAET

CONCLUSION and SUGGESTIONS

This paper presents an example lesson plan for middle school students on thermal insulation by incorporating the engineering design process. The lesson plan is research-based and student-centered. Students work in small groups and conduct research to propose several solutions, choose the best alternative, collect data, and make decisions regarding their design. Additionally, they learn from failure and suggest ideas using their scientific knowledge about thermal insulation to improve their designs. These elements in the lesson plan are considered valuable to foster 21st-century skills such as problem-solving, critical thinking, and creativity. Moreover, the lesson plan included information about engineering careers and how engineers work. The discussions regarding visuals related to engineers, using engineering terminology, and filling out an Engineering Notebook are effective ways for students to develop engineering design skills, such as how the group of engineers communicates, works together, and proposes solutions to real-life problems. Students gain an understanding of how the design challenge is connected to relevant scientific knowledge about thermal insulation at the end of the lesson.

During the implementation, teachers should pay attention to keeping up with the steps of the engineering design process properly because students tend to skip researching the problem and proposing more than one solution to the problem, as suggested by the relevant literature (Crismond & Adams, 2012). Researching the problem part might be enriched by using educational technologies since we had limited opportunities in our case. Additionally, science and mathematics concepts should be featured in choosing the best solution (Peterman et al., 2017). Lastly, students' science and engineering related-misconceptions should be addressed and overcome in the activity, such as heat and temperature are the same, there is only one successful engineering design (Hynes et al., 2011), and engineers work alone (Fralick et al., 2009).

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Appendix 1

Engineering Notebook

1. Identify the problem given in the scenario:

____
____
____

Fill in the table below regarding the criteria and limitations to which you should pay attention to solve the problem.

CRITERIA	LIMITATIONS

2. Research the Problem:

In accordance with the information cards given to you, note the typical characteristics of thermal insulators in the box below.

Common Characteristics of Good Thermal Insulation Materials

----

3. **Develop possible solutions:** You need to develop at least two solutions (brainstorm, discuss, and develop possible solutions).

Solution 1	**Solution 2**
Solution 3 (If any)	**Solution 4 (If any)**

4. **Select the best solution:**

Decide which of the solutions you propose would best solve the problem. Why do you think this is the most appropriate solution? Write your reasons in the last column.

Solutions	Do the thermal insulation materials heavy?	Are the thermal insulation materials you choose quickly burning?	Is the life cycle of thermal insulation materials long?	Are thermal insulation materials have lower thermal conductivity?	Do the cost of the thermal insulation material appropriate?	Why do you think it is the best solution?
Solution 1						
Solution 2						
Other Solutions (If any)						

5. **Construct a prototype:**

- Firstly, draw your prototype and note the materials you want to use on your drawing with the help of an arrow. Then, create your prototype using the materials.

- **The budget of the prototype: ……. TL.**

6. **Test and evaluate the solution:**

- Identify one of your group members as a data analyst.
- In order to test, you need to take five different measurements.

Initial Temperature (^0C)	After 5 min (^0C)	After 10 min (^0C)	After 15 min (^0C)	After 20 min (^0C)	Temperature Change (Last measurement-first measurement)

7. **Communicate the solution:**

- Share your solution with your friends. Explain how the proposed solution meets the given problem.

8. Re-design:

Complete the table below by considering testing and communicating the solution.

The Strengths of the Design	The Weaknesses of the Design	The Points that should be Improved in the Design

Appendix 2

Information Cards

Wool Fabric

Characteristics
- resistant to heat
- long-life span
- has lower thermal conductivity
- frequently used in cloths and textile
- durable

Cost in the activity: 8TL (one package).

Aluminium Foil

Characteristics
- resistant to heat
- long-life span
- lightweight structure and high reflectivity
- moderately durable, generally used between layers of other insulation materials
- widely applicable in roofing, walls, or windows
- relatively waterproof and easy to shape
- good for health

Cost in the activity: 8 TL (one package)

Bubble Wrapping Nylon

Characteristics
- resistant to heat
- long-life span
- used in steel, glass, pharmaceutical, electronics, white goods and furniture industries.
- hollow structure
- water resistant and durable

Cost in the activity: 10 TL (one package)

Cotton

Characteristics
- not resistant to heat
- long-life span and eco-friendly
- wide range of uses in the chemical industry, oil industry and artificial textiles
- readily absorbs water
- has a lower thermal conductivity
- moderately durable

Cost in the activity: 9 TL (one package)

Fibre

Characteristics
- not resistant to heat
- long-life span
- used as raw material in many industrial branches, especially in textile industry
- prone to water absorption
- good for health

Cost in the activity: 10 TL (one package).

Sponge

Characteristics
- resistant to heat
- long-life span and lightweight
- flexible and inside pores contain air
- supplement other insulation materials
- absorbs water easily

Cost in the activity: 9 TL (one package).

Cling Film

Characteristics
- not resistant to heat
- long-life span
- transparent plastic material used for wrapping various substances in order to eliminate their interaction with air
- generally used in windows, water resistant and lightweight

Cost in the activity: 6 TL (one package).

Felt

Characteristics
- resistant to heat
- long-life span
- has many uses, from clothing to the automotive industry
- has lower thermal conductivity
- has a dense, compact structure
- resistant to moisture

Cost in the activity: 8 TL (one package).

Fiber Glass Wool

Characteristics

- resistant to heat, wool-like structure
- often used in buildings, especially in walls, ceilings, and floors
- lightweight, not degrade over time
- has a lower thermal conductivity
- can cause some potential health problems by direct contact

Cost in the activity: 12 TL (one package).

Glass

Characteristics

- resistant to heat
- can be brittle and prone to breaking
- healty for human
- high thermal conductivity

Cost in the activity: 6 TL (one cup).

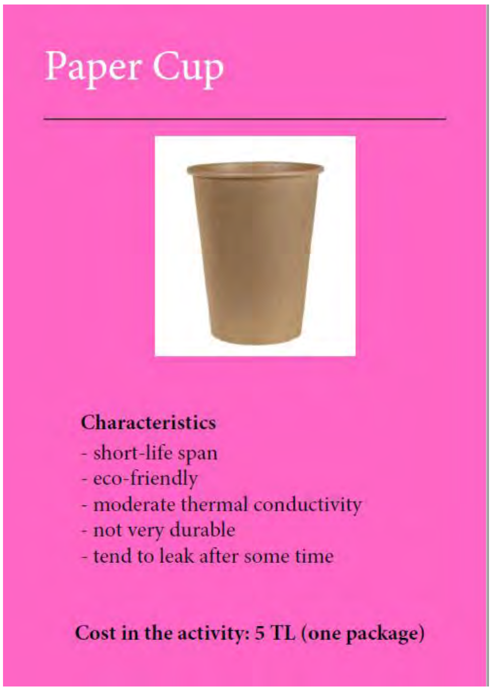
Styrofoam Cup

Characteristics

- not resistant to heat
- long-life span
- water resistant
- lower thermal conductivity
- reasonably harmful when used with hot food and drinks

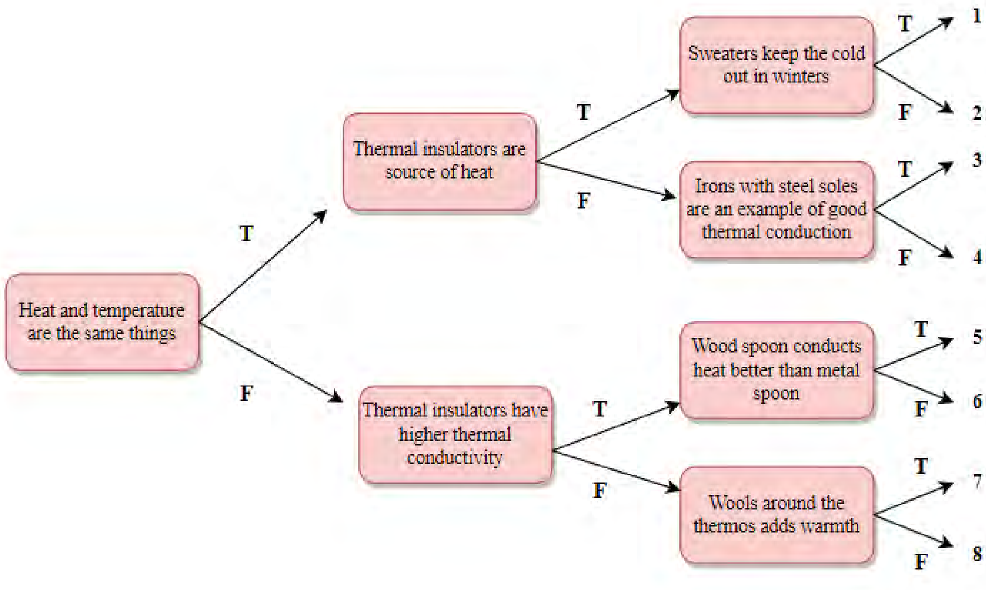
Cost in the activity: 7 TL (one cup).


Plastic Cup
Characteristics
- resistant to heat
- moderately durable
- retain heat for longer periods of time
- not eco-friendly
Cost in the activity: 5 TL (one cup).


Paper Cup
Characteristics
- short-life span
- eco-friendly
- moderate thermal conductivity
- not very durable
- tend to leak after some time
Cost in the activity: 5 TL (one package)

Appendix 3

The Diagnostic Tree



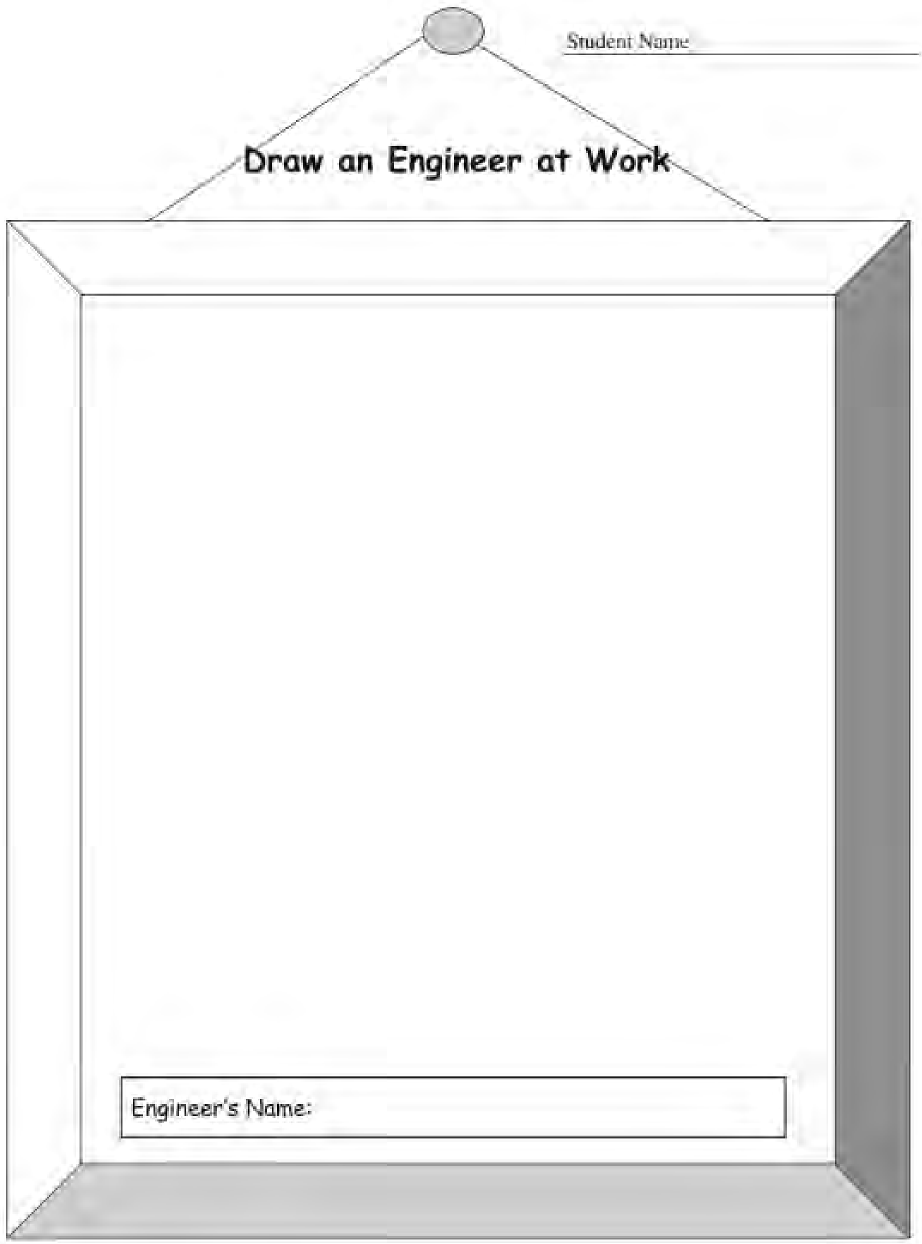
Appendix 4

Rubric for Assessing Engineering Notebook

Qualifications	Very good (2)	Good (1)	Should be improved (0)
Determining Criteria	The five criteria for the problem are determined correctly and completely.	Some criteria for the problem are determined as correct but incomplete.	The criteria for the problem are not determined.
Determining Limitations	The two limitations of the problem are determined correctly and completely.	One of the limitations of the problem is determined as correct, but the other one is incomplete or wrong.	The limitations of the problem are not determined or are determined wrong.
Researching the Problem	More than four characteristics of thermal insulation materials are provided correctly.	Two or three characteristics of thermal insulation materials are provided correctly.	Only one characteristic of thermal insulation materials is provided or no information about them is determined.
Developing Possible Solutions	The group members develop at least two solutions for the problem.	The group members develop a single solution for the problem.	The group members do not develop a solution for the problem.
Determining the Best Solution	It is determined by addressing the criteria and limitations.	It is determined without addressing the criteria or limitations.	It is not determined.
Creating the Prototype	The sketch is provided, and the functioning prototype is created.	Either sketch or functioning prototype is missing.	No sketch and prototype are created.
Testing the Solution	The temperature change of the thermos is calculated, and the table is filled in completely.	The temperature change of the thermos is miscalculated, or the table is filled in incompletely.	The temperature change of the thermos is not calculated, and the table is empty.
Communicating the Solution	The design is presented in accordance with all of the given criteria and limitations.	The design is presented in partial compliance with the given criteria and limitations.	The design is presented without considering the given criteria and limitations.
Re-designing	The strengths and weaknesses of the design and the points that should be improved are indicated.	One of the strengths or weaknesses of the design or the points that should be improved are indicated are missing.	At most, one of the strengths or weaknesses of the design or the points that should be improved are indicated is indicated.

Appendix 5

Draw an Engineer Test (DAET)



Describe Your Engineer

Personal Information: ______________________________

____

____

____

Work Setting: ______________________________________

____

____

____

Job Description: ___________________________________

____

____

____

What is the engineer in your drawing doing?

____

____

____

____

____

Appendix 6

Checklist for Draw-an-Engineer Test

Appearance of Scientist / Engineer

Species:
- ☐ Human
- ☐ Non-Human
- ☐ No Person

Gender:
- ☐ Male
- ☐ Female
- ☐ Unknown

Skin Color:
- ☐ Brown
- ☐ Peach
- ☐ Yellow
- ☐ Green
- ☐ None
- ☐ Other: ______________

Other Attributes:
- ☐ Crazy Hair
- ☐ Glasses / Goggles
- ☐ Lab Coat
- ☐ Laborer's Clothing
- ☐ Appearance Other: ______________ ______________

Location
- ☐ Indoors
- ☐ Underground
- ☐ Outdoors
- ☐ Underwater
- ☐ Space
- ☐ Can't Tell

Inferences of Actions
- ☐ Making/Fixing/Working with Hands
- ☐ Operating/Driving Machines & Vehicles
- ☐ Designing/Inventing/Creating Products
- ☐ Experimenting/Testing/Creating Knowledge
- ☐ Other: ______________________________
- ☐ Explaining / Teaching
- ☐ Observing
- ☐ No Action Inferred

Objects
- ☐ Other People (total # _______)
- ☐ Non-Humans - monsters, etc.
- ☐ Body Parts – parts in jars, brains, etc
- ☐ .Robots
- ☐ Computers
- ☐ Building Tools – wrench, hammer, etc
- ☐ Measuring Tools – rulers, etc.
- ☐ Writing Objects – papers, pens, etc.
- ☐ Studied Animals
- ☐ Other Animals
- ☐ Studied Plants
- ☐ Other Plants
- ☐ Rocks
- ☐ Passenger Vehicles
- ☐ Construction Vehicles
- ☐ .Flying Vehicles
- ☐ Rockets / Space Vehicles
- ☐ Trains / Tracks
- ☐ Other: ______________________________
- ☐ Fictional Machines
- ☐ Other Machines
- ☐ .Books
- ☐ Furniture – tables, chairs, etc.
- ☐ Math Symbols
- ☐ Chemical Symbols
- ☐ Blueprints, Drawings and Graphs
- ☐ Diplomas / Awards
- ☐ Weapons – guns, bombs, etc.
- ☐ Keep Out / Beware Signs
- ☐ Danger – fire, explosions, etc.
- ☐ Civil Structures – bridges, buildings, etc.
- ☐ Chemistry - flasks, test tubes, etc.
- ☐ Technology - TVs, radios, phones, etc.
- ☐ Medicine - germs, syringes, needles, etc.
- ☐ Meteorology
- ☐ Sports
- ☐ Signs of Thinking

Drawing Information

Student ID Number: ____________

Pre / Post: ____________

Drawing Type: ____________

Year: ____________

Evaluator ID: ____________