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Students' Experiences of Design-Based Research in Science Applications Course: A Design and Development Research

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Abstract

The purpose of this study is to examine students' experience of design-based research in science applications courses. The study was carried out during the fall semester of the 2018-2019 academic year in the science application course. The participants of the study were 44 eighth grade students attending in two classes of a secondary school located in Odunpazarı district of Eskisehir. In the study, a design-based research method was used. The students were asked to describe a problem from daily life during the application phase of the study. Afterwards, they were expected to design products to solve this problem. Data collection tools of this study were the Reflection Form for Design Steps, which was developed by the researcher, and the Self-Assessment Form included in the Technology Design Course Curriculum. The application was completed in an eight-week period. Content analysis was used to analyze the obtained data. It is seen that students have mostly departed from their own life in the identification of the problem, and the ideas that they have generated were about problem solving, new ideas, and making life easier. Students followed the stages of the design process such as research, design, problem identification, and drawing sketches. Regarding the evaluation of their experience during the design process, most of the students stated that they learned how to design, but they found it difficult to combine materials. Students stated that next time they would pay more attention to choosing design features, identifying the problem, and finding interesting products. Research can be carried out to examine the skills that are thought to be effective in the design process such as decision making, critical thinking, and problem solving. Within the scope of the 2023 Education Vision, it is planned to establish "Design-Skill Workshops". With such an application, students' design skills can be improved.

Key words: Science applications, design-based science education, design and development research, content analysis

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INTRODUCTION

Howard Gardner states that our children need to be equipped with the knowledge and skills to do the jobs that "machines cannot do". Gardner's warning actually emphasizes the importance of "twenty-first century skills" (Aydeniz et al., 2015). P21 (Partnership for 21st Century Learning) grouped twenty-first century skills under three main categories: Learning and Innovation; Skills, Information, Media and Technology Skills; and Life and Career Skills (P21, 2015). Skills such as creativity, innovation, critical thinking, problem solving, communication and cooperation, information and communication, technology, literacy, flexibility, entrepreneurship, productivity, and responsibility are among the skills expected from students today. Students who have acquired the skills of the twenty-first century may increase the global competitiveness of their country by contributing to its economy (Williams, 2011). In addition, STEM training, which includes integration of many disciplines such as science, technology, engineering, and mathematics, is a necessity in gaining twenty-first century skills (Aydeniz et al., 2015). Science, engineering, and technology are pervasive in modern life and play an important role in solving the current and future problems of humanity (National Research Council, [NRC] 2012). Many countries in the world such as America, England, Germany, Austria, Finland, S. Korea, and China attach importance to STEM education (Dugger, 2010; Norris, 2010; Parliamentary Office of Science and Technology [POST], 2013). Moreover, in many reports, it is stated that especially science, technology, engineering, and mathematics should be integrated into the curriculum and educational practices at all grade levels (National Academy of Engineering [NAE], & National Research Council [NRC], 2009; Next Generations Science Standards [NGGS], 2013). STEM was first used by Judith A. Ramaley in the 1990s, as an acronym for Science, Technology, Engineering, Mathematics (Bybee, 2013; Breiner, Harkness, Johnson, & Koehler, 2012; Dugger, 2010; Sanders, 2009). STEM education is an interdisciplinary approach that deals with science, technology, engineering, and mathematics in an integrated way (Dugger, 2010). According to Dugger (2010), in STEM education the disciplines are not presented in a way that they are dependent on each other, but rather intertwined as in everyday life; thus, it enables students to perceive the world as a whole. According to Breiner et al. (2012), in STEM education, the objective is to educate the individual as a real-life engineer, scientist, or technologist and to enable the individual to gain experience in the learning environments in which these applications are applied. These individuals, who have this education, are expected to combine the theoretical knowledge gained from the science and mathematics disciplines with technology and engineering and launch new products.

STEM education provides multidimensional learning by bringing different disciplines together and linking these disciplines (Smith & Karr-Kidwell, 2000). It mainly focuses on the science and mathematics disciplines, but it also includes technology and engineering (Bybee, 2010), which constitute the application areas of science and mathematics (Yamak, Bulut, & Dindar, 2014). Technology provides people the opportunity to use their science and mathematics knowledge to improve their living standards and solve the problems they face (Cavanagh & Trotter, 2008). Engineering is defined as the design process of the man-made world (NAE & NRC, 2014). The report published by NAE and NRC (2009) shows design as the most important dimension of engineering. Design is defined as the cyclic decision-making process used to optimize human resources or goal-oriented problem-solving activity (Smith, 1988). Design is also seen as a tool with which scientific knowledge and real-world problem-solving skills can be improved (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004). In addition, a problem solving approach is used in the engineering design process (Green, 2012). The engineering design process serves to know something new, learn how it works, use existing knowledge to create new things, and make them suitable for others (Brophy, Klein, Portsmore, & Rogers, 2008).

This process involves certain stages outlined as follows. The first stage of the engineering design process is the phase of "describing the problem". Understanding the design problem contributes to the determination of the criteria and limitations of the product that will be the solution for the problematic situation (Hynes et al., 2011; Kolodner, et al., 2003). At the stage of "specifying the requirements of the problem", students have to conduct research on the product they have to design (NAE & NRC, 2009). In the "development of possible solutions", the objective is to generate as much as possible solutions for the design problem by brainstorming (Brunsell, 2012; Mentzer, 2011). After this stage comes “select the best solution” (Brunsell, 2012; Hynes et al., 2011; Mentzer, 2011, NRC, 2012; Silk and Schunn, 2008). At the stage of “building the prototype (first product)”, engineers produce a prototype to present their designs visually or to show its details (NRC, 2012). In a way, building the prototype can be considered as the equivalent of the application of solutions that was developed by the engineers in theory, so this stage is important for the development of the design (Mentzer, 2011; NRC, 2012). At the stage of “presenting the solution”, engineers can share their ideas about all stages of the design process with each other (Brunsell, 2012; Hynes et al., 2011; NRC, 2012). During the “retest” stage, engineers make improvements to make the product better (Hynes et al., 2011). At the “finalizing the decision”, engineers or students decide whether their final design is the best solution (Hynes et al., 2011).

The steps related to the engineering design process vary. Students who follow the five stages of Engineering is Elementary” (EiE) program design “offer solutions to an engineering problem, imagine, plan, create and develop” (Cunningham, 2009). Jamerson's design process has four stages, namely planning, design, control, and sharing (Barger, Gilbert, Poth and Little, 2005). At the planning stage, the design problem is described, the problem is investigated, and the restrictions and requirements of the design are clarified. At the design stage, design alternatives are produced, the best option is selected and the reason is explained, and then a design model or prototype is developed. At the control stage, the design solution is tested and evaluated, but the design can be changed to meet the evolving needs. In the sharing stage, the product is launched. In the engineering design process, the problem is identified, a research is performed, the requirements are determined, the solutions are evaluated through brainstorming, a prototype is developed, the solution is tested, how the solution met the requirements is tested, and the results are shared (Wells, 2016).

In the literature, the approaches that use the engineering design process in science education are referred as “design-based science education” (Altan, Yamak, & Kirikkaya, 2016; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005; Wendel, 2008; Wendell & Rogers, 2013). Design-based science education is a method in which scientific knowledge is constructed in the context of design creation (Fortus et al., 2004; 2005).

The studies in the literature involving the design process were conducted with teachers, pre-service teachers, and students. In the studies conducted with teachers, their engineering perception was analyzed (Hsu, Purzer, Cardella, 2011; Marulcu & Sungur, 2012; Yasar, Baker, Robinson-Kurpius, & Roberts, 2006), their opinions about the engineering design process were collected (Capobianco, 2011; Cuijick, Keulen, & Jochems, 2009), and the engineering design process was combined with the science content (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Capobianco, 2013; Felix, 2010). The studies conducted with pre-service teachers involved their perspective towards the engineering process (Marulcu & Sungur, 2012; Sungur Gul & Marulcu, 2014) and the process of using engineering design in the course (Bozkurt, 2014). The literature review showed that there are few studies on engineering applications in science education conducted with pre-service teachers.

Regarding the studies conducted with students, the focus was on learning (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008; Ellefson, Brinker, Vernacchio, & Schunn, 2008; Ercan & Sahin, 2015; Fortus et al., 2004; Marulcu, 2010; Schnittka & Bell, 2011; Yasak, 2017; Wendell, 2008). In addition there are studies investigating the effect of the engineering design process on problem-solving skills (Fortus et al., 2004; Pekbay, 2017), decision-making skills (Ercan, 2014), and creativity (Doppelt, 2009). There are also studies conducted with students in which the engineering design process was applied to a subject and a product was built at the end of the process (Penner, Giles, Lehrer, & Schauble, 1997; Roth, 2001; Sadler, Coyle and Schwartz, 2000; Tal, Krajcik, & Bluemenfeld, 2006; Kolodner et al. 2003). In the research carried out by Penner, et al. (1997) students were assigned to comprehend science-related modeling by designing three-dimensional products. A total of 48 students from the first and second grades made a functional human elbow model with the help of materials provided by the teacher. In the research conducted by a total of 26 students from the sixth grade (10 students) and seventh grade (16 students) about simple machines, Roth (2001) matched design activities that students perform with engineering applications and described the product design stages to be carried out as follows: developing the first draft and construction of the plans; illustrating these plans in slides, graphs, tables; building a three-dimensional prototype; performing and analyzing performance tests; and finally presenting the final product. Sadler, et al., (2000) asked students to improve the prototypes presented to them in their research. Tal et al. (2006) started their study with a guiding question, "Why should bikers wear helmets?" and then asked students to develop a mini helmet to protect the eggs carried in a small toy car. Kolodner et al. (2003) conducted a comprehensive analysis of the design-based research process in their research. In the study, where the implementation steps to be followed during the course were clearly stated, eight-week teaching activities of the "Vehicles in Motion" unit took place as an example.

In recent years, understanding of the interdisciplinary interaction in education has been emphasized. In addition, science, engineering, and entrepreneurship applications have been added to the curriculum. In the science curriculum, scientific process skills, life skills, and engineering design skills are covered in a specific skills section (Ministry of National Education [MEB], 2018a). The science curriculum is based on a research-based learning approach with an interdisciplinary perspective. The learning process covers exploration, inquiry, argument creation, and product design. Students are expected to recognize the problems addressed in the previous units, describe the problems, identify alternative solutions, compare these solutions, determine the most appropriate one, build a product, and present this product in the most effective way. In addition, scientific process skills, life skills, and engineering and design skills are emphasized under field specific skills. Analytical thinking, decision making, creative thinking, entrepreneurship, communication, and team work are mentioned under the life skills. It is seen that among these skills, decision making, creative thinking, communication and team work are also used in the engineering design process. In addition, with engineering design skills, students are encouraged to develop products by using the knowledge and skills they have already acquired and develop strategies on how to add value to these products by integrating science with mathematics, technology, and engineering, thus providing students with an interdisciplinary perspective and bringing them to the level of making invention and innovation (MEB, 2018a).

The engineering design process, which is emphasized in the curriculum of science education, also takes place in the curriculum of technology and design course and science applications course. In the technology and design course curriculum, the innovative thinking skill is a way of thinking that pioneers new insights, original approaches, new perspectives, and new ways of understanding and comprehending something. In general, what is important to develop innovative thinking is using the techniques that enable the production of ideas, the banding of different ideas, an education based on idea generation, the free use of the imagination, and the development of thinking skills (MEB, 2018b). In the science applications course curriculum, there is also a certain gain related to Product Creation and Entrepreneurship, such as "applying 'engineering design and entrepreneurship process' to product creation" (MEB, 2018c). The engineering design process includes the stages of describing a problem departing from daily life or industrial needs, generating possible solutions for the problem, comparing them and selecting the appropriate solution according to the criteria, designing and presenting the product, developing strategies for marketing the product, and launching the product (MEB, 2018c). It is seen that there is a common emphasis on the engineering design process in the curriculum of science, technology, and design and science applications courses.

Students who have acquired engineering and design skills will be able to produce solutions to complex real-life problems. Therefore, students should be provided with more experience in the engineering design process. This process can be integrated into courses as emphasized in teaching programs. There are some studies with students where the engineering design process was applied on a specific subject and products were built at the end of the process. However, in this study, students were not restricted to a specific subject area. Within the scope of this study, students were asked to design products by applying engineering design processes during the science practice course. Therefore, this study is designed as a design and development research. In this study, the aim was to

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examine the design-based research experiences of the students in a science applications course. For this purpose, the following question was addressed.

- What are the experiences of secondary school students in design processes?

METHOD

Research Design

In this study, Design and Development Research (DDR) was used. This research is the systematic analysis of the design, development, and assessment stages to establish the basis for the production of new models for educational or noneducational products, tools, and development models based on scientific evidences (Richey and Klein, 2007, p.748). At the same time, this research is a flexible research method for improving educational researches, where analysis, design, development, and implementation processes are carried out in collaboration by the researchers and participants, in a real practice environment (Wang & Hannafin, 2005). The reason for preferring this research approach in the study was to develop the solution for an existing problem and improve the functioning of the design in practice. This development approach involves the development, implementation, and assessment of innovative processes, designs, and products in the research process (Buyukozturk, Cakmak, Akgun, Karadeniz, & Demirel, 2018).

Study Group

The study was carried out during the fall semester of the 2018-2019 academic year within the scope of the science applications course. Forty-four eighth grade students attending two classes of a secondary school located in the Odunpazarı district of Eskisehir participated in the study. In fact, there were a total of 50 students in two classes (26-24). However, six students (four from the first class and two from the second class) were not willing to participate in the study. Thus, we ended up with a total of 44 students, 22 from each class, participating in the study. Fifty-nine percent (n = 26) of the participants were female and 41% (n = 18) were male. In this study, criterion sampling from the purposive sampling methods was used where taking the science applications elective course was considered the basic criterion.

Research Process

In the 2018 science applications course curriculum, the applied science unit is covered under the science and engineering learning area. Therefore, at the beginning of the application, the problems of daily life and the design examples developed to solve the problems are mentioned. Afterwards, students were asked to describe a problem from daily life. In order to help to clarify the problem description, a form including 5W-1H questions (what the problem is, how the problem is experienced, why the problem is experienced, where the problem is experienced, when the problem is experienced, and by whom the problem is experienced) was prepared by the researcher and technology design teacher. This form, which has been prepared for the purpose of investigating, describing, and discussing the problem, was given to the students at the beginning of the application. Students were expected to make sketches of the design they intended to develop in order to solve the problem. In this process, the science teacher, technology design teacher, and researcher provided guidance to the students. At the end of the application, they were expected to design products to solve the problem. The application was completed in an eight-week period.

Data Collection Tools

In this study, Reflection Form for Design Steps, which was developed by the researchers, and Self-Assessment Form for Technology Design Process were used.

Reflection form for design steps

In order to determine students' ideas about the design process, a semi-structured reflection form was developed by the researcher about the design steps. Reflection Form for the Design Steps consisted of five dimensions, namely asking, imagining, planning, creating, and developing. There were four questions in each subdimension and 20 questions in total. While developing this form, a technology design and a science teacher were consulted. After the expert opinions were noted, the final version of the reflection form consisted of a total of 10 questions (two questions in each dimension).

Self-assessment form

The self-assessment form was included in the 2013 Technology and Design Course curriculum and consisted of 7 questions. The form includes questions such as What I learned in this activity, What I did well, What was challenging, When I needed help, in which area should I develop myself?, What are my strengths and weaknesses?, and What I shall do differently in further studies. Before using the form, a technology design and a science teacher's opinions were elicited. Through this form, students were expected to perform a self-assessment regarding the design process. The form was given to the students after the application, and they were asked to fill it out. Self- assessment forms were collected after the application.

Data Analysis

In qualitative research, the researcher reads the data one by one, obtains codes and categories, and presents the results of the research based on these codes and categories (Merriam, 1998). Content analysis was used to analyze the data obtained from the reflection and self-assessment forms. In this process, an inductive approach based on continuous comparative data analysis was applied (Strauss and Corbin, 1998). First, each data was coded with open coding and then the coded data was categorized according to its content considering the relationships among the codes. Then, all categories were summarized and explained under certain themes (Miles and Huberman, 1994). Finally, the data was reported with direct quotations from the answers. In the research, a code was given to each student, and the identity of the participants was kept confidential by using them in direct quotations taken from the opinions in reporting.

In this process, to ensure the validity of the research, direct quotations were taken from the opinions of the students about the design process. In addition, the stages of the research were explained in detail (Miles & Huberman, 1994). For the reliability of the research, the researcher met with two technology and design teachers and a science teacher twice. In the first session, researchers and teachers coded the data separately and checked the compliance in coding (Creswell, 2013). The differences arising from the differentiation of the codes were determined and discussed to reach a common understanding. In the second session, the appropriateness of the assignment of the data into categories was checked. In addition, the researcher and a faculty member, experienced in qualitative research, made separate coding on the data obtained from the reflection and self-assessment forms and the consistency ratio was calculated by comparing the codes. The researcher refrained from adversely affecting the data collection process as well.

In the analysis of the data obtained from the reflection form for the design steps, five stages of the engineering design process, which were determined by Cunningham (2009), were used. These steps are: offering solutions to an engineering problem, imagining, planning, creating, and developing. The data obtained from the self-assessment form were analyzed under the following categories: learning, doing, challenges, getting support, self-development, strengths & weaknesses, and assessment.

While analyzing the data, the statements of the students related to the research purposes were included in the analyses. The quality of some of the students' answers did not meet the required quality, thus these statements were excluded from the analysis.

FINDINGS

In this section, the findings obtained from the analysis of the reflection form for design steps and the self-assessment form for design process, determining the experiences of the secondary school students of the design processes, are given.

Findings from the reflection form for design steps

In the analysis of the data obtained from the reflection form for the design steps, five stages of the engineering design process, which were determined by Cunningham (2009), were used. These steps are: offering solutions for an engineering problem, imagining, planning, creating, and developing. The data obtained from the self-assessment form were examined under the following categories: learning, doing, experiencing challenges, getting support, developing self, determining strengths and weaknesses, and being assessed (Table 1).

Table 1. Category, Code and Frequencies Obtained from the Reflection form for Design Steps

Theme	Category	Code	Frequency
Describing the problem	What is the source of the problem	His/her life	36
		Other people's life	11
	Ways of identifying the problem	Observation	24
		Research	22
		Interview	6
		No opinion	3
Imagining	Product design priorities	Being problem solving oriented	20
		New ideas	19
		Facilitating the life	18
		Functional	14
		No opinion	10
		Fulfilling the needs	7
		Being economical	6
		İmproving energy efficiency	3
Planning	Inspired products	Mechanic	27
		Electric and Electronics	21
		None	5
	Steps considered	Research	19
		Design	16
		Identifying the problem	15
		Drawing sketches	10
		Determining the materials	8
		Making plans	4
		Product assessment	4
Creating	Material specifications	Suitable for design purpose	26
		Economical	5
		Practical	5
		Robust	4
		Environment friendly	3
		Ergonomic	2
		Recyclable	2
		No opinion	6
	Problems experienced	No problem encountered	14
		Combining the materials	12
		Material selection	8

		Decision making	5
		Drawing sketches	1
Development	Compatibility with initial specifications	Similar	35
		Not similar	9
	Assessment	Positive	47
		Being practical	22
		Being economical	9
		Being original	8
		Being functional	8
		Negative	15
		Being impractical	6
		Being uneconomical	4
		Spending much energy	4
		Not original	1

Describing the problem category covers the source of the problem and the ways to identify the problem. The students stated that they mostly departed from their own lives when identifying the problem related to the design process. A student told on this issue "*I've identified the problem while putting water from the cup into the pot (P4)*", another opinion supporting this one was "*Even though we wipe the mirror, the dust remains on. And I have to wipe it all the time (P6)".* Another opinion was "*I specified the problem while I realized how it was tiring when I was picking up my desk (P7)*". Departing from his/her own life was followed by departing from other people's lives. A student's opinion about the departure from other people's lives was "*The fact that people cannot use the Internet efficiently and the electricity prices are very high (P9)*", whereas another opinion was "*The army will be protected by the ballistics of my system if they get stuck in mine-type destruction systems in operation or on duty (P18)*".

The students stated that they mostly identified the problem by observation. A student said "*I have mostly focused on my own problems when identifying the problem. I didn't look at any particular data (P11)*", whereas another opinion supporting this one was "*While identifying the problem I departed from the problems that I experience personally (P7)".* Observation was followed by research. On this issue a student said "*I searched the Internet for the foreign language learning rate of the people in the world and how much challenge they have and I determined my product in accordance with my research (P3)*", whereas another opinion supporting this one was "*I searched the Internet. Looking at the results of the research I envisaged the application in my mind (P37)".* Students stated that they had got opinions from their surroundings, their friends, and their families by interviewing while identifying the problem. There are also students who did not comment on this subject.

The imagination category includes product design priorities. Regarding the product design priorities of the students, it is seen that they are mostly problem solving oriented. A student expressed his/her opinion about problem solving as "*I think about its properties, and it can be done with two flashlights and a hoodie (P23)*", whereas another one said "*Since the earrings were made of metal, I decided to make a magnet device that could attract them (P30)".* In addition, product design priorities of the students include being new ideas, facilitating life and being functional, fulfilling the needs, and being economical. In terms of new ideas, a student wanted to develop a product that would ensure that cars do not hit the barriers. Another student thought to integrate a device into a book. For making life easier, a student thought to design a product to prevent food spoilage in the refrigerator, whereas another student designed a bench that did not get wet. The product developed for preventing food spoilage and its sketch are shown in Figure 1, whereas the bench that wouldn't get wet is presented in Figure 2.

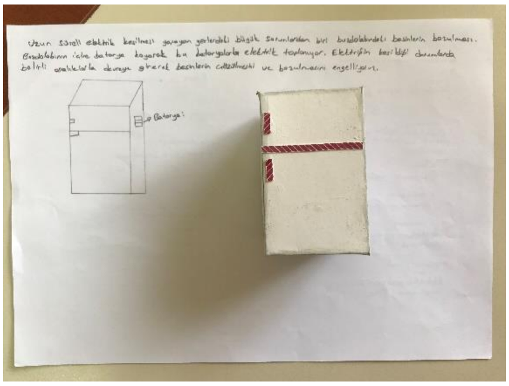

Figure 1: The product developed for preventing food spoilage and the sketch

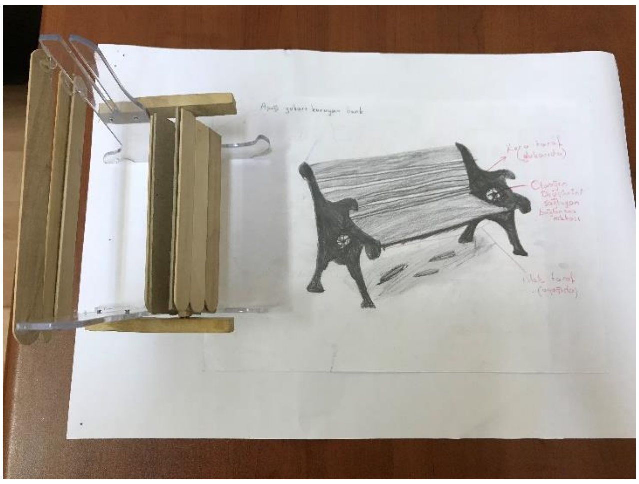

Figure 2. The bench that wouldn't get wet and the sketch

A student said about functionality "People usually choose smart products now. That's why I wanted it to be a smart application, able to talk and communicate with people (P37)", whereas another student (P16) stated that he planned it to be functional. Regarding fulfilling the needs, a different student stated that he determined product specifications "departing from the problems and needs of people (P28)". About being economical, one student thought to use plastic material, another student thought to initially use a sponge instead of a magnet and a different student thought to use the most appropriate material in terms of cost. The product samples developed by the students who thought to be economical were the garbage-pull (Figure 3), the nondirtying ice-cream (Figure 4), and the funnel facilitating fluid transfer (Figure 5).

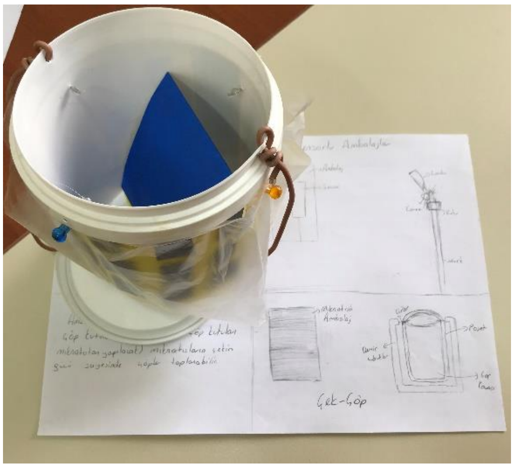

Figure 3. Garbage-pull and the sketch

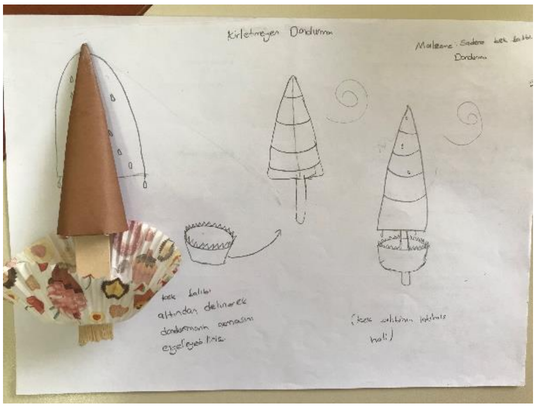

Figure 4. Non-dirtying ice-cream and the sketch

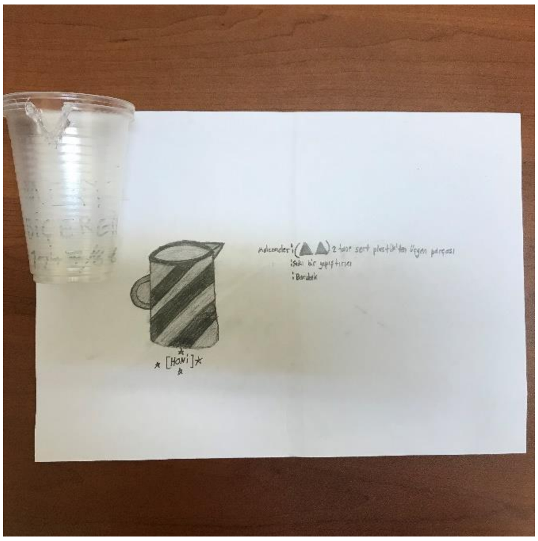

Figure 5. Funnel facilitating fluid transfer and the sketch

For increasing energy efficiency, a student wanted to develop a machine that satisfies heat need by blowing steam and using solar energy in the process. The product and the sketch are given in Figure 6. There are also students who do not have any opinions on this issue.

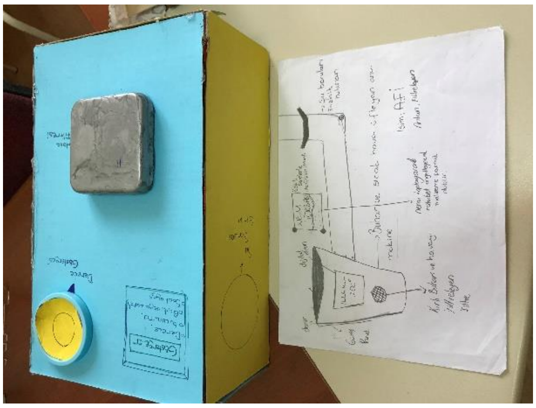

Figure 6. A machine that satisfies heat need by blowing steam and using solar energy in the process and the sketch

The imagination category includes the inspired products and the steps taken into account. Students have had very different ideas when developing products, and they were inspired by various tools and materials used in daily life. Inspired products are divided into two in terms of working principles, mechanical products, and electric-electronic ones. It is seen that among these tools used in daily life, they mostly preferred mechanical ones (e.g. umbrellas, magnets, insulation materials, headphones, wagons, tables, funnel, bench, sponges). This was followed by electric-electronic products (television, clock, voice recorder, heated blanket, applications in play store). However, there are students who did not use any product. The steps that students mentioned they considered during the development of the product were doing research, creating a design, identifying the problem, drawing sketches, determining the materials, making plans, and evaluating the product. A student's opinion about research was "*I first identified my problem and then I explored how this problem can be facilitated by today's technology and developed the product I found (P20)*", whereas another opinion supporting this was "*I researched the Internet and asked some people their ideas and made plans (P31)*". Regarding the design, a student expressed his/her opinion as "*First of all, we have chosen the topic and designed it in our minds (P27)*". Another student's opinion about material determination was "*First, I identified the materials needed for the product* (P12)". About identifying the problem a student said, "*First, I have identified the problem. Then I determined how to solve it and this product appeared (P29)*", whereas another opinion on this issue was "*I first identified the problem, then I developed solutions and designed my product (P28)*". For drawing sketches a student expressed his/her opinion as "*I've identified the problem and made drawings, sketches for it (P32)*", whereas another opinion supporting this was "*Then I found the solution and made the sketches (P16)*". The properties of the materials used in building products and the problems encountered were examined under the category of creation. While determining the properties of the materials that they used, students told that they mostly considered materials that were in accordance with the design. On this issue, a student stated that he/she used "*Strong magnets and sensors (P14)*". A different opinion on this issue was "*I used more heat-resistant materials because my product was working with heat (P20)*". Being suitable for design was followed by being economical, convenient, robust, environment-friendly, ergonomic, and recyclable. A student expresses his opinion about being economical and useful as follows: "*I tried to select the most useful and cost-effective materials for my product (P16)".* Another student stated that he/she used *"ergonomic materials (P15)".* In terms of recyclability a different student said "*I planned to use materials in other similar applications (P37)*".

Regarding the problems encountered while building the product, the majority of the students stated that they did not encounter any problems. On the other hand, some students stated that they had difficulty in combining the materials, material selection, decision making and drawing sketches. A student expressed his/her opinion about combining materials as "*I had difficulties in combining the materials I have chosen during the product construction. This could only be managed by getting help from an adult (P1)*", whereas another student stated his/her opinion as "*I have problems in sticking the tongue bar to the stand with silicone in the construction of the product (P11)*". Another opinion supporting these was "*I had difficulties in keeping the balance while building, but I handled this with more glue (P16)*". Regarding the selection of the appropriate materials, a student expressed his/her opinion as "*I had some trouble in the construction phase because of the big size of the product, but then I solved this problem by getting help from my family (P7)*", whereas another student expressed it as "*The screen I mounted on the wristband was unable to scan larger objects. I've solved this problem by using a light scanner, not a screen on the wristband (P35)*".

The development category includes compliance with the initial characteristics and assessment codes. While evaluating their products, students often stated that their products were in line with the specifications initially determined. A student expressed his/her opinion as "*I built the same product that I originally designed (P13)*", whereas another one stated his/her opinion as "*I designed it in the same way as the product I determined (P8)*". A student stating that his / her product was not similar to the specifications he/she initially determined said, "*For example, I normally should have one cylinder but I thought it was not enough and added one more (P20)*". Another student expressed his/her opinion as "*It was more amateurish and less solid. The materials I used differed (P16)*".

The students found the products they designed mostly positive when evaluating them in terms of similar products. These positive thoughts have been mostly in terms of being practical, being economical, being original, and being functional. Regarding being practical, a student said that the product that he/she designed was "*more useful and easier to use compared to other products (P7)*". A different student (P30) expressed the cost-effectiveness aspect of his/her product as follows: "*It is cheaper than similar products*". Another student expressed the originality of his/her products with the following words: "*Since my product was designed from zero, it has no similarity with any other product (P1)*". Another opinion that supports this opinion is "*My product is unique in this world (P34)"*. A student expressed his/her opinion about functionality as "*I produce as much electricity as I need with the product I designed (P8)"*.

Negative opinion includes being impractical, uneconomical, lacking in energy efficiency and unoriginal. About being impractical, a student expressed his/her opinion as "*Among negative aspects, it doesn't appeal to all people (P26)*", whereas another student said about much energy spending "*It is a product that over-uses electricity; except for this, all aspects are positive (P5)"*. The opinion of a student about being uneconomical is "*When it is produced professionally, the cost can be higher than similar products (P16)*".

Findings from the self-assessment form for design process

The data obtained from the self-assessment form were evaluated within the scope of the following questions: what I learned, what I did well, where I was challenged, when I needed support, what I need to develop, what were my strengths and weaknesses, and what to pay attention to in later designs (Table 2). In the evaluation of their experience during the design process, students stated that they mostly learned how to design. A student expressed his/her opinion on this issue as "*I have learned to imagine and design a product (P3)*", whereas another said "*In this activity, I learned to design a new product according to a problem I identified (P35)*". Another opinion supporting these was "*I learned how to make a product in this activity (P37)*". Other subjects that they had learned were problem solving, planned work, improvement needs, research, innovation and recycling awareness. About problem solving a student said, "*There is a solution to every problem (P40)*"; another said he/she has learned "*To find a solution to problems (P29)*". Regarding planned work a student expressed his/her opinion as "*We can get a new product with planned work (P26)"*, whereas another one said that he/she learned planned work. About improvement need, a student felt that he/she could believe in him/herself and do something. There were also students who did not express any opinion on this issue.

Table 2. Questions, Analysis Codes and Frequencies of the Self-assessment Form

Questions	Analysis Codes	Frequency
What I learned?	Design	17
	Problem solving	14
	Planned work	8
	Improvement needs	5
	Research	2
	Innovation	2
	Recycling awareness	2
	No opinion	1
What I did well?	Design	23
	Problem identification	8
	No opinion	5
	Material selection	4
	Problem solving	3
	Drawing sketches	3
	Research	1
Where I was challenged?	Combining materials	14
	Problem identification	13
	Lack of challenge	7
	Material selection	5
	Design	5
	Drawing sketches	3

	No opinion	3
	Research	2
	Decision making	3
When I needed support?	Combining materials	22
	Lack of help	7
	Design	5
	Research	3
	Material selection	3
	Finding solution	3
	Creating sketch	1
	No opinion	1
What I need to develop?	No opinion	9
	Combining materials	7
	Drawing sketches	6
	Problem solving	6
	Problem identification	5
	Design	3
	Field knowledge	2
	Research skills	2
	Creative thinking	2
	Flexible thinking	2
	All areas	1
	Material selection	1
	Working fast	1
	Anxiety control	1
What are my strengths and weaknesses?	My strengths	
	No opinion	15
	Design	10
	Problem identification	8
	Drawing sketches	4
	Combining materials	2
	Research	2
	My weaknesses	
	No opinion	24
	Problem identification	6
	Drawing sketches	4
	Execution	4
	Material selection	3
	Research	3
	Creativity	2
What to pay attention to in later designs	No opinion	13
	Identifying design specifications	11
	Problem identification	8
	Finding interesting products	7
	Material selection	4
	Planning	3
	Research	2
	Drawing sketches	2

Most of the students considered the design as something they did well. A student expressed his/her opinion on this issue as "*I did my design well. Because I chose the items about which my imagination is strong (P27)"*, whereas another student said "*I built the product well. Because I have understood the design phases of the product very well (P7)*". This was followed by problem identification, material selection, problem solving, drawing sketches, and research. With regard to problem identification, a student (P12) stated that he/she had identified the problem well. Another student's opinion supporting this was "*I think I've done well in the idea phase. Because I have done a useful design that people can carry out easily (P35)*". A different student (P32) thinks that he/she was good in selecting materials. Another student (P6) said that he did a good sketch because he worked hard at his drawing. There were also some students who did not feel that they did anything well and did not give any opinions.

Students stated that they mostly had difficulty in combining materials and problem identification. A student expressed his/her opinion on combining materials as "*It led to putting more silicone in the parts where the silicone gun couldn't keep it (while sticking the tongue bar to the stand with silicone) and that's how I was challenged (P11)*", whereas another student (P19) told that he/she had difficulty in gluing and bonding. A student expressed his/her opinion on problem identification as "*I had a hard time in identifying the problem. Because I didn't know what to do having the qualities we want to use (P26)*"; another opinion supporting this was "*in identifying the problem. Because there are a lot of problems around me (P29)*". Problem identification was followed by a lack of challenge, material selection, design, drawing sketches, research, and decision making. There are also students who did not have any opinions on this issue. A student expressed that he/she did not have difficulty at all with these words: "*I wasn't challenged in any issue (P3)*". A student expressed his/her opinion on material selection as "*I had trouble in finding the materials required for my product (P18)*". A different student expressed the challenge that he/she had experienced on drawing sketches with these words: "*I had difficulties in drawing. Because at first I could not imagine exactly what I would do (P20)*".

The students mostly expressed the need for support in combining materials. A student expressed his/her opinion on this issue as "*Since I had difficulty in combining the materials I selected, I got help at that stage (P1)*", whereas another student said, "*I needed help combining product parts (P7)*". Another opinion supporting these was "*When I was doing the cone, I couldn't do it at first, thus I got help from the Internet (P2)*". Even though there were students who did not get help on this issue, there were ones who got support in the design, research, material selection, finding solutions, and drawing sketches stages. One student stated that he did not receive any help during the construction stage as "*I didn't need any help (P4)*". Another student (P29) told that he/she had help in design, while another student (P28) said that he/she needed help doing the research. A student expressed his/her opinion on material selection as "*Because I didn't know the types of materials, I asked them for help (P20)*".

It can be seen that the majority of students did not express their opinions about improvement need. The subjects on which the students expressed their improvement need were mostly combining materials, drawing sketches, problem solving, and problem identification. A student's opinion about combining materials was "*The parts that are compatible with each other can be more easily combined when they are joined together (P1)*". Regarding drawing sketches, another student wanted to improve putting his/her ideas down on paper and in drawings; another opinion supporting this was "*I have to improve myself more with drawing what I designed (P27)*". Regarding problem identification, a student criticized him/herself as "*I should think more comprehensively when finding a problem (P26)*", whereas another student self-criticized as "*I have to improve myself in creating solutions (P38)*". These are followed by design, field knowledge, research skills, creative thinking, flexible thinking, all areas, material selection, working fast, and anxiety control.

A student expressed his/her opinion on the design as "*I have to improve myself more in the product design phase (P7)*". A student who thinks about improving him/herself in field knowledge expressed his opinion as follows: *"The working system of that pulley was really hard for me (P5)*". A different student expressed his/her opinion on the material selection issue as *"A smaller product can be developed by using smaller parts to improve the design (P1)"*.

When students were asked about their strengths and weaknesses, most of them did not express any opinion. On the other hand, students who wrote their opinions considered themselves strong in terms of design and problem identification. This was followed by drawing sketch, combining materials, and research. A student expressed his/her opinion on the design as "*I like to deal with design (P23)*". Another student said the following about problem identification: "*As my strength, I can say that I'm good at finding the problem (P1)"*. The opinion of the student saying that he/she is good in drawing sketches was: *"My strengths are drawing and converting the drawing into the product (P16)*". Regarding weaknesses, problem identification, drawing sketches, application, material selection, research, and creativity were mentioned. A student having difficulties in problem identification expressed his/her opinion as "*I've had a hard time finding the subject (P17)*". Another student believing to be weak in drawing sketches said "*My drawing on paper is not very good (P7)*", another opinion supporting this was "*I'm better at thinking, but I'm not really good at making a drawing (P27)*". A student expressed his/her opinion on the application as "*I think my weakness is to transfer the product into real after drawing the design (P1)*". Another student's opinion on material selection was "*I'm good at paper, but I'm bad at choosing materials (P6)*". A different student (P3) emphasized the weakness of his/her research aspect. Another student expressed his/her opinion on the creativity as "*My weaknesses are creativity (P35)*".

The students mostly said that they would pay more attention to choosing the features of the design in the next study. They also stated that they would focus more on identifying the problem, finding interesting products, choosing materials, developing themselves, planning, doing research and drawing sketches. A student expressed his/her opinion on choosing the specifications of the design as "*I'll make my materials and design a little smaller (P7)*", whereas another student said "*I will make it more powerful; it will generate more electricity (P9)*". Another opinion supporting these was "*In my next work, I'm thinking of adding different features like sound and color (P35)*". A student expressed his/her opinion on problem identification as "*I'll find a better idea (P42)*", whereas another student said "*I'm going to find a better idea, I'll make a better project, and I think it will be nice (P17)*". Regarding finding interesting products, a student said, *"I think I'm going to make the hoodie my authentic design (P23)"*. A student expressed his/her opinion on material selection as "I'll produce the refrigerator with a better material (P13)". Another student (P2) has emphasized that he/she will work in a more planned and temperate way. A student expressed his/her opinion as "*I will do more systematic research and design (P18)*".

DISCUSSIONS AND CONCLUSIONS

In this study, students were expected to experience engineering design processes in a science application course. At the beginning of the application, problems of daily life and design examples developed for the solution of the problem were mentioned. Afterwards, students were asked to identify a problem from daily life and expected to design a product in order to solve the problem. Their experiences in this process were examined.

According to the statements obtained from the reflection form for design steps, it was found that students mostly departed from their own lives when determining the problem related to the design process. The students stated that they identified the sources that they used in the process through observation and research. Regarding students' product design priorities, it was found that they mostly generated ideas about the products serving to solve the problem. This was followed by being a new idea, facilitating life activities, being functional, fulfilling needs, being economical, and increasing energy efficiency. About making life easier, a student thought to design a product to keep food in the refrigerator from spoiling, whereas another student designed a bench that did not get wet. The product samples developed by the students who desired to be economical were a garbage-pull, nonspilling ice-cream, and a funnel that facilitates liquid transfer. In order to increase energy efficiency, a student wanted to develop a machine that satisfies heat needs by blowing steam and using solar energy in the process.

Students have had very different ideas when developing products, and they were inspired by various tools and materials used in daily life. Among these tools used in daily life, the ones working with mechanical principles were most preferred. This was followed by electric-electronic tools. The students stated the steps they considered in the emergence of the product as research, design, problem identification, drawing sketches, and material determination. While determining the material specifications, students stated that they mostly paid attention to using the features appropriate for the design purpose. Regarding the problems encountered in product production, the majority of the students stated that they did not encounter any problems. However, in this study, in which 44 students participated voluntarily, only five of the students were able to perform all the steps of product design. Other students got stuck in the early stages of the design development process, which, in fact, is a clear indication that they encountered difficulties. However, the fact that the majority of the students stated that they did not have any difficulty shows how weak their self-assessment or self-awareness was. Among 44 students, only five of them showed the performance of designing a product, which shows that the engineering design skills that were tried to be taught to the students were not learned by the majority of students. Although there is a possibility that the teaching methods in this course were not effective, it is thought that the main problem is the lack of instructional contents that would develop such qualities in the students in the early stages of the education system. There is a need for the contents that will enable students to develop critical thinking, observation, exploration of problems, and problem-solving skills to be taught from earlier grade levels. Fortus et al. (2004) emphasized that engineering is not only a design process but a process that involves individuals who encounter design problems to experience learning in which they gain scientific inquiry and problem-solving skills in the solution process. In this study, students stated that they experienced difficulties in combining materials and choosing suitable materials. In the assessment of their products, students mostly stated that their products fit the specifications that they initially determined. When evaluating the products they designed in terms of similar products, students found them positive.

According to the data obtained from the self-assessment form, students stated that they mostly learned to design and solve problems while evaluating their experiences related to the design process. The other subjects that the students learned were problem solving, planned work, improvement needs, research, innovation, and recycling awareness. In the study of Ercan (2014) in which design-based science education practices have been carried out, it was found that students improved in all the following stages of engineering design process application skills: “identification of the problem or need”, “look for possible solutions”, “determination of optimal solution”, “prototype construction and testing”, and “communication”. This finding of the study overlaps with the findings of the study by Ercan (2014). The evaluation of the findings of these two studies shows that students' experience in design development leads to new learning. In this study, students mostly thought that they were good at design and problem identification. In a study by Bozkurt (2014), where the effect of engineering design-based science education on science pre-service teachers' decision-making skills, scientific process skills, and perceptions about the process was examined, it was observed that at the end of the process, pre-service teachers felt themselves strong about thinking skills, design, and producing new ideas. The findings of the study by Bozkurt support the findings of this study. In this study, students mostly stated that they had difficulty in combining materials and problem identification. On the other hand, in a study applying design-based science education in teacher education, it was found that pre-service teachers had difficulty in the following stages of the engineering design process: developing the possible solutions, construction of the prototype, choosing the best solution, and defining the problem (Altan et al., 2016). In a study conducted by Capobianco (2011) on the application of engineering design approach by science teachers in science courses, it was found that teaching science courses through design was both interesting and sometimes difficult for students. The findings of these studies show that not only the students but also the teachers and pre-service teachers were challenged during the implementation of the design processes. Technical support could be provided to students to improve their performance in design processes. Studies could be done to support their thinking skills so that they can progress in a healthier way. Deficiencies in field knowledge could be completed. Design experiences could provide students with valuable opportunities to improve their understanding of both science content and scientific practice. However, the application of design-based science learning in the classroom presents a number of important challenges (Vattam & Kolodner, 2008). Thus, in a study by Vattam and Kolodner, (2008), in order to overcome the challenges faced by design-based science learning technology, additional support was provided by offering software designs.

In this study, the students stated that they mostly received support for combining materials and design. When the improvement needs of the students were asked, it was seen that most of the students did not express opinions. Regarding the students who expressed their opinions, the issues that they needed to develop included combining materials, drawing sketches, problem solving, and problem identification. When their weaknesses and strengths were asked, most of the students did not express any opinion. On the other hand, students who expressed opinions considered themselves strong in design and problem identification. Weaknesses included problem identification, drawing sketches, application, material selection, research, and creativity, respectively. The areas in which students perceived themselves as weak in their assessments were in fact mostly overlapped with the areas in which they had difficulty. Therefore, it is considered that it would be beneficial for the students to attend support trainings which would strengthen these aspects. In a study by Doppelt (2009), it was found that design-based learning supports students' creative thinking skills. This finding supports the findings of this study. The stages that pre-service teachers showed low performances on while developing engineering design-based teaching activities were the ones such as "problem identification", "finding creative solutions", and "modelling the solutions" (Topalsan, 2018). This suggests that education programs are weak in developing individuals' design skills. The students stated that they would pay attention to determining the specifications of design in the next study. They also stated that they would focus more on identifying the problem and finding interesting products.

As a result of this research, it can be seen that students used their own experience while identifying the problem for the design process, but at a lower rate they could also identify the problem by receiving inspiration from the experiences of other people. Regarding product design priorities of the students, it was found that the characteristics such as being problem-solving oriented, being a new idea, making life easier, and being functional were emphasized more. In the answers about the stages of the design process that students used, it was found that they mostly emphasized research, design, problem identification, drawing sketches, and material determination. Regarding the answers given by students about what kind of materials they preferred to use in their designs, they mostly preferred to use materials that were suitable for design purposes, followed by economical and useful materials. Considering this finding together with the students' findings about product design priorities, students gave priority to the appropriateness of materials to the design stages both at the stage of imagination and at the stages of creation. While evaluating their experience in the design process, students stated that they mostly learned to design, but they had difficulties in combining materials. Students stated that in the next study, they would pay attention to choosing the specifications of the design, identifying the problem, and finding interesting products.

With this study, students experienced the stages of the engineering design process and had an idea about what to do when developing a new product. It is thought that students' awareness about their problems and the problems in their surroundings was improved with this study. Students had the opportunity to evaluate themselves after their design development experience and they became aware of what to pay more attention to in the subsequent design processes.

In this study, students were expected to design a problem from daily life and design a product for the solution of the problem. However, it was observed that most of the students had difficulty at the early stages of the design development process. In the new program, the content that will improve students' problem-solving skills should be prepared starting from early grade levels. In a report by NAE and NRC (2009), it was indicated that the integration of engineering into the curriculum will improve learning and achievement in science, mathematics, engineering studies, and engineering awareness. In addition, it will strengthen the ability to understand and deal with engineering design and will develop sustainable interest in engineering as a career. Lastly, it will provide significant opportunities for increasing technology literacy.

In future studies, a particular subject could be set and students could be asked to develop products related to this subject. As a characteristic of design tasks, Crismond (2001) stated that design tasks should be related to a limited number of science and engineering acquisitions. For this reason, particular gains could be chosen in studies to be done for design-based science education. Research could be carried out to examine the skills that are thought to be effective in the design process, such as decision making, thinking, and problem solving. Within the scope of the 2023 Education Vision, it is planned to establish "Design-Skill Workshops". With such an application, students' design skills could be improved. This study was limited to a science application course, 50 eighth grade students studying in two classes of a secondary school in the 2018-2019 academic-year fall semester, and the qualitative data collection tools used. This study can be conducted with different samples, different data collection tools, different courses (or integration of different courses), and at different grade levels.

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