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Concepts of creativity in design based learning in STEM education

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Abstract
Creativity is deemed as an integral part of twentyfirst century skills and is emphasized in science education curricula in Turkey as well as in other countries. Therefore, the purposes of this research were to examine the concepts of creativity demonstrated in the developing possible solutions step of the DBL and to determine the students' perceptions of this step. Data were collected from 13 female and 11 male middle school students participated in three different design based learning activities. Analyses of the data derived from students' writings and drawings, semi-structured interviews, and researchers' field notes were carried out using two separate methods. Descriptive analysis was used to quantitatively analyze students' writings and examine the fluency, flexibility, originality, and elaboration concepts of creativity while content analysis was used to qualitatively analyze the semi-structured interviews and researchers' field notes to corroborate the results of the descriptive analysis. Findings indicated that students demonstrated the highest frequency in fluency concept of creativity while the lowest frequency in originality. Also, the results of the content analysis revealed that the creativity of the students' ideas were influenced by several reasons including the exposure to other students' ideas, the degree of the familiarity with the design based learning process, and the fact that students had to make a working prototype of their ideas. Educators and future researchers might benefit from the findings of this study while using DBL to develop creativity as well as the suggested creativity assessment technique to determine students' strengths and weaknesses in this process.

Keywords Creativity · Design-based learning · Engineering design process · STEM

> *Creativity is the key to education in its fullest sense and to the solution of mankind's most serious problems.*
>
> *J. P. Guilford.*

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Introduction

In today's world, the rapid technological, economic, social, and global changes (Beghetto 2015) require creative thinking as a crucial skill to survive and adapt to changes In the 1990s, Nokia was one of the most-profited mobile phone companies in the market. Nokia's falling behind the competition in the 2000s is attributed to its shortcomings in creative design (Valjak 2017). K-12 school systems face a similar challenge when children's curious and creative ideas are not valued.

In the literature, different definitions of creativity have been offered. Of these definitions, the most leading one might be of Guilford's (1950) in which he described creativity as "the abilities that are most characteristic of creative people" (p. 444). He further referred creativity as "the key to education in its fullest sense and to the solution of mankind's most serious problems" (1967bb, p. 13). The relevant literature also suggests that creativity is viewed as the ability to produce new, surprising, and valuable ideas (i.e., poems, recipes, and scientific theories) or artifacts (Boden 2004), innovative, task/problem-relevant, and high-quality products (Kaufman and Sternberg 2007), an idea, act, or product changing an existent domain or transforming an existent domain into novel one (Cszikszentmihalyi 1996), and a socially noticeable novel and useful product (Plucker, Beghetto, and Dow 2004).

Considered as a key factor driving civilizations forward (Hennessey and Amabile 2010), creativity plays a central role in current educational contexts (Lasky and Yoon 2011). This is because K-12 students in the creativity-centered classroom learn to identify and solve open-ended problems, cope with the changing world (Parkhurst 1999), be prepared for the ever changing jobs of the future, and practice skills to make inventions, discoveries, and art (Kress and Rule 2017). Moreover, since younger students were found to be more creative than older students (Conradty and Bonger 2018), the provision of creativity-centered education in the K-12 classroom may reinforce students' creative thinking skills and help them maintain high level of creativity (Charyton 2014; Cooper and Heaverlo 2013; Denson 2015; Henriksen 2014).

Integration and assessment of creativity in the K-12 classroom

The central role of creative thinking in today's world has driven educators to integrate creativity into the K-12 classroom. Drawing attention to the importance of creativity, Cropley (1997) listed the requirements of a creative classroom as offering constructive criticism, encouraging students' independent thinking, making time for students to follow up their ideas, and allowing students to try out new ideas by inspiring students to solve problems using as many ways as possible rather than insisting on a certain way. Sternberg (2003) noted that students should be motivated to create, invent, discover, explore, imagine, and suppose in order to develop a creative attitude toward life. Starko (2014) pointed out three key factors when developing creativity in the classroom; (1) teaching the nature of creativity and strategies for developing creative ideas, (2) teaching the creative individuals in the disciplines, (3) and developing a creativity friendly classroom. In the light of these factors, he added that divergent thinking strategies, the use of metaphors and analogies, visualization and creative dramatics, and commercial and competitive programs might be some of the ways to develop creativity in classrooms. Analysing the characteristics of creative learning environments, Jindal-Snape et al. (2013) noted that such learning environments should be both physically and pedagogically flexible, encourage students to control their own learning, allow them experience in- and out-of-school learning environments, free the students from pressure, and let students use time flexibly.

The initiation of creativity assessments overlapped with divergent thinking tests (Kaufman et al. 2008). Therefore, defining divergent thinking would be meaningful before we discuss the metrics of creativity and the ways to assess it. Guilford (1967a) described divergent thinking (production) as; "…a concept defined in accordance with a set of factors of intellectual ability that pertain primarily to information retrieval and with their tests, which call for a number of varied responses to each test item" (p. 138).

Guilford suggested a model named Structure of Intellect Model (SOI) in which he proposed 24 types of divergent thinking that can be used to assess creativity. After the term "divergent thinking" was introduced to the literature, most of the attempts for assessing creativity were shaped around this concept and used all around the world (Kaufman et al. 2008). Guilford's (1950, 1967a) early research regarding divergent thinking tests and SOI model introduced the concepts of fluency, flexibility, originality, and elaboration to the creativity assessment literature. The first concept, fluency, refers to the number of ideas, solutions, or answers and it is simply the retrieval of information. The second concept, flexibility, indicates the number of different categories of ideas, solutions, or answers and it leads to the classification of the information (Kaufman et al. 2008). The third concept, elaboration, focuses on the richness of the content describing each item (Horowitz 1999). Elaboration can lead to new implications and produce chain-like thinking (Guilford 1967a, b). Finally, the fourth concept, originality, is related to the uniqueness or statistical infrequency of the responses (Horowitz 1999) as well as the production of new forms and patterns (Guilford 1967a). Guilford's idea of examining the creativity using these concepts were so highly embraced that it has been adapted by numerous researchers in various fields including general creativity (Wallach and Kogan 1965; Torrance 1974; Urban 2005), mathematics (Tan 2015), science (Diakidoy and Costantinou 2001; Endean and George 1982), and engineering (Horowitz 1999). These concepts evolved into the metrics of creativity, which underscored that large scale applications of creativity assessment have launched with the metrics of divergent thinking (Kaufman et al. 2008).

Another way of assessing creativity, a reliable subjective assessment technique, namely Consensual Assessment Technique, was based on the expert's ratings of products. Amabile (1982) noted that when conducting this technique all judges should be familiar enough with the domain to recognize a creative product, all evaluations should be independently conducted, all products should be evaluated in some other dimensions such as technical aspect and aesthetic appeal in addition to the creativity, all products should be rated in relation to other products, and each judge should view the products in different order. Originally Amabile (1982, 1983) applied this technique to rate artistic and verbal creativity.

STEM education and creativity

Creativity is deemed as an integral part of twentyfirst century skills and is emphasized in science education curricula in Turkey as well as in other countries (Ministry of Education 2018). Therefore, the need to support creative thinking in the classroom is often highlighted in the literature (Charyton 2014; Cooper and Heaverlo 2013; Denson 2015; Henriksen 2014). In this regard, STEM educational approach defined as integrating two or more disciplines when solving real-life problems (Sanders 2009; Shaughnessy 2013; Smith and Karr-Kidwell 2000) has the capability to improve students' creative thinking skills.

Harris and Bruin (2018) noted that STEM Education has been focusing on creativity and suggested that experimental research should be conducted to determine ways to improve creativity in STEM Education. In another theoretical study, Henriksen (2014) stated that the interdisciplinary nature of STEM, as it builds on the integration of science, mathematics, engineering, and technology, also helps students apply their knowledge from different disciplines to create a new product. Therefore, STEM education is one of the most important approaches to develop creativity. Nemiro et al. (2017) implemented robotics in STEM education with 194 elementary students over a 3-year period. In this exploratory observational study, the students worked intensely on open-ended robotics challenges. They found that robotics may improve students' creativity. Furthermore, they underlined the need for developing new tools or ways to assess or examine creativity in STEM education. Biçer et al. (2017) conducted a research with 95 high school students in- and out-of-school learning environment. In this study, the students made 3D computer-aided designs using engineering design process, and the researchers examined the students' perceptions about the need for creativity in STEM. They used a structured survey as a data collection tool and found that the change in students' perceptions of the need for creativity in STEM was statistically significant.

Creativity in STEM education through design based learning

Used as a common approach in STEM education, design based learning (DBL) builds on the integration of the designing process of real-life engineers into the classroom applications to solve real-life problems (Felix 2010). Students need to acquire scientific, mathematical, and technological skills to solve these real life problems by using engineer-like designs considered as tools providing real-life context for both science and mathematics learning. DBL approach enables students to transfer a knowledge base to complex problems (Bozkurt Altan 2017; Mehalik et al. 2008; Moore et al. 2014), motivates students, and improves their engineering knowledge through experiencing the design process (Marulcu 2014; Mehalik et al. 2008; Moore et al. 2014; Hmelo et al. 2000). Given this overall ground, it is evident that DBL approach is based on engineering design process and it would be helpful to define it.

Engineering design is a process (National Academy of Engineering [NAE] and NRC [National Research Council] 2009; NRC 2012) described in various models in the related literature (Brunsell 2012; Hynes et al. 2011; Mentzer 2011), and most of these models shared five steps in common. The first step of the engineering design process begins with identifying the problem (Brunsell 2012). The design challenge usually starts with a real life problem. In this step, engineers define the problem, the criteria (characteristics or features that a successful design should include), and constraints (challenges or obstacles that prevents a design from being successful) that should be considered to solve the problem (Hynes et al. 2011). It is only possible to create a successful solution when the problem is clearly defined. Similarly, students are provided with a clearly defined problem so that they experience the same process as engineers do. After the provision of the problem, students are allowed to spend some time to fully comprehend the problem, set the criteria required for a successful design and constraints that prevent students from building a successful design (Brunsell 2012). Developing possible solutions is the second step of engineering design process that requires the creative thinking most (Denson 2015; Valjak 2017). At this step, students should generate as many ideas as possible based on the criteria and constraints required to solve the problem (Brunsell 2012). The third step is choosing the best solution. In this case, students discuss how each solution meets the criteria and constraints of the problem (Hynes et al. 2011) or worked around the constraints. Lee and Kolodner (2011) stated that creative designer or problem solver should think about different solutions and how the solutions of similar problems might be applied to the solution of the given problem. Considering this statement, these two steps, developing possible solutions and choosing the best solution linked the design challenge to creativity. In the making a prototype and testing the solution step, students must create a prototype which is a report or model (physical, virtual, or mathematical) of the final solution and test their solutions based on the constraints and criteria of the problem to judge whether their prototype is successful or not (Brunsell 2012). In the final step, communicating, students share their ideas and findings with other students to receive feedback as engineers do with other engineers (Mentzer 2011).

Researchers emphasize that creativity is an integral part of the engineering design process (Awang and Ramly 2008; Charyton 2014; Denson 2015; Howard et al. 2008; Hynes et al. 2011; Lou et al. 2017; Siew 2017; Tekmen-Aracı and Mann 2019) and without some concept of creativity in design there is no potential for innovative solutions and production where novel ideas are implemented especially in the classroom. Creativity is the major influence on the solutions or products developed for the design challenges. Furthermore, the challenge provided in the engineering design process needs to be open-ended to facilitate a creative learning environment. The design process offers special opportunities for students to use their creativity because of the ‘‘openness’’ of challenges (Cropley and Cropley 2010). If the emphasis is only on the correct solution, students’ originality and creativity can be diminished (Chin 1997). Creativity includes the concepts of fluency (number of ideas), flexibility (number of categories of solutions), originality (the novelty of ideas), and elaboration (the detailedness of ideas). Because in the second step of the engineering design process (developing possible solutions) students are expected to develop as many (fluency), original (originality), and different (flexibility) solutions as possible (Brunsell 2012; Hynes et al. 2011) this step is the ideal step for students to employ creative thinking in this process.

The importance of creativity has been highlighted in many studies about engineering and STEM education (Charyton and Merrill 2009; Charyton and Snelbecker 2007; Cropley and Cropley 2005; Kowaltowski et al. 2010) as well as in studies focusing on improving students’ creativity (Chasanah et al. 2017; Hathcock et al. 2015; Keana and Keana 2016; Mayasari et al. 2016; Siew 2017; Syukri et al. 2017). Keana and Keana (2016) suggested design based learning in STEM education as a way to develop creativity. The ill-defined design challenges and product oriented learning process of design based learning align with the nature of creativity. The study of Siew (2017) showed that the STEM-Engineering Design Process approach can be applied as a means for fostering creativity, problem solving skills, and thinking skills among rural secondary school students. In another study, findings indicated that a creative product is influenced by pre-service physics teachers’ STEM knowledge (Mayasari et al. 2016). Mayasari et al. (2016) found that the flexibility, fluency, originality, and elaboration of the participants’ products improved in each concept respectively after 15 lessons of design learning. In another study, students’ products were assessed using creative thinking skills assessments based on the concepts of fluency, flexibility, originality, and elaboration (Chasanah et al. 2017). The study showed that elaboration was the concept that students received the highest score for their products. Syukri et al. (2017) found that DBL activities were effective for middle school students to demonstrate the creativity concepts in the prototypes of their solutions, and originality of the students' technical prototypes received the lowest score among the creativity concepts. Hathcock et al. (2015) examined the effect of inquiry based questioning strategies on creativity in DBL. They implemented design based activities in both experimental and control groups. However, in experimental group they also used inquiry based questioning strategies. They used Consensual Assessment Technique to determine the creativity level of the product and found that inquiry based questioning strategies in DBL help students develop more creative products. They suggested that teachers' assistance matter when developing creative ideas. Lasky and Yoon (2011) found that after an implementation of out-of school DBL project teachers thought DBL can be used to develop creative thinking skills in schools.

Significance of research

Designing products with STEM activities provides opportunities for students to develop creativity (Chasanah et al. 2017; Hathcock et al. 2015; Mayasari et al. 2016; Siew 2017). To determine the effectiveness of design activities in regard to creativity, educators and teachers need to assess the level of creativity. Some of the traditional divergent tasks could be used in design based learning process to assess creativity however traditional divergent thinking tests involving fluency, flexibility, originality, and elaboration concepts require a tool or task that is predeveloped and structured (Endean and George 1982; Mayasari et al. 2016; Torrance 1974; Urban 2005; Wallach and Kogan 1965). The method of Diakidoy and Costantinou (2001) might be an option to assess creativity in a science field through the evaluation of ill-defined problems, however they only scored the concepts of fluency and originality and their sample consisted of university students. Chasanah et al. (2017) assessed creativity of the process and product through the fluency, flexibility, originality, and elaboration in DBL. However, it was very difficult to determine the procedures they followed when scoring the process or product due to the lack of clarification. Subjective methods such as Consensual Assessment Technique and teacher views could also be used to assess creativity in DBL as Hathcock et al. (2015), Lasky and Yoon (2011) and Syukri et al. (2017) did. However, even though these methods might have some grounds for reliability, the creativity scores obtained using these methods might differ from scorer to scorer due to their subjective nature. This study differed from the previous ones assessing creativity concepts in DBL in several ways and therefore would make an important contribution to the field. The technique researchers suggested in this study did not require a specific predesigned tool or task. Rather, it could be used in assessing the fluency, flexibility, originality, and elaboration of possible solutions in any design based activity with no limitation in age, setting, material, or discipline. This technique might be more suitable to be used as an objective assessment and the creativity scores obtained using this technique might less likely to differ from scorer to scorer due to the clearly defined concepts and examples of scoring. Furthermore, the studies mentioned above focused on either the entire process of DBL or only the product. However, a knowledge gap existed on how creativity concepts appeared in students' solutions and what the students thought about this process. This study filled the gap by specifically focusing on the developing possible solutions step of DBL which was underlined as the step enables the use of creativity the most (Denson 2015; Valjak 2017). Hence, the purposes of this research were to examine the concepts of creativity demonstrated in the developing possible solutions step of the DBL and to determine the students' perceptions of this step. To achieve these purposes, following research questions were sought to answer:

1. To what extent did students demonstrate creativity concepts when developing possible solutions in design based learning?
2. What were the students' perceptions of developing possible solutions process in design based learning?

Methodology of research

General background

This study was based on a case study design using a qualitative approach. Case studies are considered to be the type of research in which the researcher explores a program, event, activity, process, and/or one or more individuals in depth by collecting detailed information using a variety of data collection procedures over a sustained period of time. Case studies are the preferred strategy when "how" or "why" questions are being posed, the investigator has little control over events, and the focus is on a contemporary phenomenon within some real-life context (Yin 2002). Yin (2002) defines four types of case study design: single holistic, single embedded, multiple holistic, and multiple embedded design.

The case examined in this study was the creativity components in students' solutions developed in the developing possible solutions step of the DBL process. The unit of analysis was the groups of students. The solutions of the groups were examined based on the components of creativity but the groups were not compared. Therefore, the design of this study was considered to be the embedded single case study.

Table 1 Demographic information of the participants

Demographic info	N
Gender	
Female	13
Male	11
Schools	
Public	24
Private	–
Grade point equivalent	
High	24
Low	–
Socio-economic status	
Middle class	19
Low class	5

Sample of research

The participants of this study were 24 randomly selected middle school students selected from 103 applicants of a STEM project carried out by a university in Turkey. The demographic information of the participants was presented in Table 1.

The participants were 13 or 14 years old. As illustrated in Table 1, 54% of the participants were female and 46% of the participants were male. All students were high-achievers with a GPA of 4.5 out of 5. Eighty percent of the participants were from middle socio-economic status with an average monthly household income of $1000, and at least one parent with a college degree. Twenty percent of the students were from lower socio-economic status with a monthly household income of $600 or less and parents with no college degrees.

For the purpose of this study the students were assigned to 6 different groups of 4 students in each group. To make sure that students were assigned to groups randomly, the researchers wrote down students' names on piece of papers and drew lots to decide who went to which group. Each group was given a name as eagles, canaries, lions, bears, monkeys, and whales.

Instrument and procedures

The data of this study were collected as part of a bigger project named STEM Education for Middle School Students. This project was funded by the university. The purpose of the project was to develop conceptions and career awareness of science, technology, engineering, and mathematics disciplines of these middle school students. The data of this study were collected from twenty four students involving three different DBL activities. In total these three activities were completed in thirty sessions.

Two science teachers, a researcher with a master's degree in science education, and a researcher with a doctorate degree in science education developed these three activities for the project. When developing these activities, Brunsell (2012)'s engineering design process and the implementation of engineering design process in classrooms (design based learning) (NAE and NRC 2009; NRC 2012) were taken into account. Based on this process, first, design challenges were defined considering the criteria and constraints. These challenges included real-life context, could be solved in more than one way, and related to more than one STEM discipline. Then, instructions were built to implement the DBL process and to form the activities. Three experts reviewed the activities. Two of the experts reviewed the activities for their appropriateness for DBL. The other expert reviewed the activities for appropriateness for developing the creative thinking process and assessing creative problem solving. The experts stated that all three activities were appropriate for students' ages to implement DBL process in a real-life context. On the other hand, the experts also delivered some feedbacks to improve the quality of the activities. All three experts made some corrections on the typographical and grammatical mistakes. Other than these corrections, the main feedback for the first activity, Helping People with Visual Disabilities in Traffic, was to use a language that promotes creative thinking more and did not guide the students towards a certain thinking process. The feedback for the second activity, Don't let Cats and Dogs Dehydrate, was that the criteria for the DBL step, testing the solution should be clearer. The last activity only received positive feedback for the content.

After the feedbacks were received, the activities were revised according to the experts' feedbacks to use in the project.

The researchers monitored students throughout the activities and they made sure that the students were not only making designs but also they were learning the required and related knowledge and skills in STEM disciplines when solving the design challenges. The students needed to use their current level of knowledge in science, technology, and mathematics as well to acquire new knowledge in these disciplines to solve these design challenges. The activities used for DBL approaches were described in detail below.

Helping people with visual disabilities in traffic

First, the students discussed the difficulties that the people with visual disabilities might encounter in their daily lives. A special education doctor was present in the room to answer the students' questions. Furthermore, a small activity was conducted to build empathy for people with visual disabilities. Most students were interested in helping people with visual disabilities crossing the street without any help. Since independence is a necessity for people with disabilities, it was aimed to increase the independence of people with visual disabilities when crossing the street with the design problem. During this activity, students employed the steps of engineering design process as well as integrating these steps into science, technology, and mathematics disciplines. For example when the student in Table 2 made a prototype of one of his solutions, he needed to learn about electrical circuits, light sources, pressure, or frictional force in science, coding in technology, and algebraic calculations for making a model of the timing of the traffic lights.

Don't let cats and dogs dehydrate

In Turkey, animals, mostly cats and dogs, usually roaming freely and they live on the streets. Therefore, there is not a specific person particularly in charge of feeding these animals with food and water. In this activity, students discussed the problems that the animals might encounter when living on the street during summer. Because the project was conducted in summer, the students realized that keeping these animals hydrated should be the main concern. Thus, the design problem for students was to design a water cup. This water cup needed to be designed in a way to minimize the need of human hand for refills. The students need to consider the size of the cats and dogs to build a design with an appropriate size. Also, in this problem the students need to make accurate mathematical calculations, consider principles of science (i.e. simple machines, pressure, depth), and may use technology (coding-sensory of depth).

An environment for birds to live in

This activity was carried out in a national park located on the seasonal migration route for the birds. First, the researchers explained the characteristics of the national park and its location being on the route of the seasonal migration to students. Then, the researchers presented the population statistics of three different kinds of birds that use this route during migration and let the students discuss the change of the population based on the environmental conditions considering these statistics. Finally, the students reached the consensus that it is important for birds to have a safe shelter. Thus, they were given the names of

Table 2 Examples for the analysis of students' writings and drawings

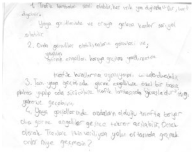
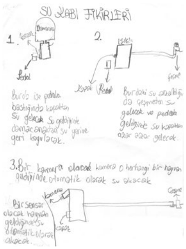
Example	Fluency	Flexibility	Elaboration	Originality
	In this example selected from the "Helping people with visual disabilities in traffic" activity, the student suggested four different solutions. For each solution, students receive 1 point. In this activity, the student developed four solutions, therefore he received 4 points for fluency	In his first solution, he offered traffic lights with sound. Each time the light changed, it would warn the individuals by saying stop or go. The second solution was to assign an employee to the traffic lights to help the elderly, and individuals with disabilities as well as to warn the ones who disobeyed the rules. Third solution was to use a pressure panel for individuals with disabilities. When the individual stepped on it, it would show up a sign for the cars in the traffic. The fourth solution was using a barrier system similar to the trains. When the individual with disability wanted to cross the street, some barriers might block the road for cars to help the individual. For each different solution, students receive 1 point. In this activity, because all 4 solutions were considerably different than each other, the student received 4 points for flexibility	The student explained all his solutions in detail. For each elaborated solution, students receive 1 point. In this activity, he elaborated on all 4 solutions, therefore he received 4 points for elaboration	When these solutions were compared with the solutions of other groups, it was found that the pressure panel idea was unique to this group and none of the other students used a pressure panel in their solution. For each original idea, students receive 1 point. In this activity, the student had 1 original idea therefore received 1 point for originality

Table 2 (continued)

Example	Fluency	Flexibility	Elaboration	Originality
	In this example, the student suggested 3 ideas for the "Don't let cats and dogs dehydrate" activity. For each solution, students receive 1 point. In this activity, the student developed three solutions, therefore he received 3 points for fluency	The first solution was a water tank with a pedal. The animal would just step on the pedal and the tank releases the water onto the water cup. Then, the student replaced the water tank with a tap in her second solution. Finally, in her third solution, the student replaced the pedal with a sensor. For each different solution, students receive 1 point. However, in this activity, all three ideas were built upon the previous one, and were not different from each other. Therefore, the student only received 1 point for first idea for flexibility, and did not receive any points for the solutions that were similar to the first idea. In other words, all similar ideas were counted as 1 point for flexibility	The student explained all three solutions in detail. For each elaborated solution, students receive 1 point. In this activity, the student elaborated on all three solutions, therefore he received 3 points for elaboration	And when these solutions were compared with the other groups' solutions, it was found that four more groups also suggested the same solutions among their other solutions. For each original idea, students receive 1 point. In this activity, all of the student's solutions were suggested by other groups and none of the solutions were unique to this group. The student had no original idea therefore received 0 point for originality

The solutions were written in Turkish. Therefore, to help the readers understand the system of scoring, the researchers explained the contents of the examples next to the images three different kinds of birds to research about so that they can build a shelter using only what is in the nature for the design problem. During this activity, the students employed the steps of engineering design process in the context of science. Also, in this problem the students should consider the size of the birds to accurately make mathematical calculations and determine the dimensions of the shelter they design.

The activities described above were conducted using DBL approaches (Brunsell 2012; Hynes et al. 2011). The groups of students started the process by defining the problem. In this step, the problems in the activities were discussed in depth so the students would understand the importance of the problem. After the students comprehended the problem, the design problems were given for students to determine the criteria and constraints for the best possible design. In the second step, the students were provided computers with internet connections to develop possible solutions. In the third step, the students in the groups evaluated the offered solutions and decided which one might be best suited for design challenge to select the best possible solution. During this step the researchers asked the students the following open-ended question "What makes you think that the design you selected was the best solution for the design problem?" In the fourth step, the students made the prototype of the design of the selected solution and they tested whether the prototype was working successfully or not. After this testing, the students discussed if there was any room for improvement for the original design. In the final step named communication, the students presented their solutions to the researchers and other groups. During the entire process, two scientists with PHD and a scientist with M.A in the science education field as well as a doctor in the gifted education field were present in the laboratory, in which the activity took place, to take field notes and answer potential questions. One of the doctors in science education field had a background in engineering design process. Also, the doctor in the gifted education field had a background in creativity.

Data sources

The quantitative data were derived from the writings and drawings of the students during the second step of the DBL, namely developing possible solutions. The qualitative part of the data were collected using field notes of the researchers, and the semi-structured interviews.

Writings and drawings of the students

The researchers asked the groups to write down, draw, or express every possible solution they have to solve the design challenge they were offered. Students were specifically asked to express their ideas in a way that they felt most comfortable. Some students listed their possible solutions in writing only and some students used drawings with little side notes to describe their solutions. Therefore, the researchers used both students' writings and drawings for their possible solutions as part of quantitative data sources.

The researchers asked students to act silently and independently when working on their possible solutions. Before students shared their ideas with their group, students were asked to write down their ideas for possible solutions on a paper. The reason for following such procedure for researchers was to prevent students from imposing their own ideas to the group and shutting down the rest of the group's creative thinking process. The students in the same group listed all of the solutions together that each of the group members thought independently. Then, the students explained both orally and in writing how they selected the solution they chose among all the designs and why they thought it was the best possible solution.

Field notes

Sherman and Webb (2005) described the field notes as the notes "provide a detailed, narrative description of what has been observed with particular attention to activities, actors, space, physical objects, and the sequence of activities and events attention to activities, actors, space, physical objects, and the sequence of activities and events" (p. 83). In this study, researchers took notes when observing the research setting, participants, and activities throughout the process, and specifically focused on the elements that might affect the creative problem solving of students. Later they compared their notes to assure that the information for qualitative data was consistent and sound in both researchers' notes.

Semi-structured interviews

Given (2008) defined semi-structured interviewing as the qualitative data collection procedure that involves asking predetermined open-ended questions. The reason why the researchers selected semi-structured interviewing as part of the data collection procedure was that in this technique the researchers were allowed to use a variety of probes to clarify the answer or elicit more elaborated information regarding the topic (Given 2008). The researchers reviewed the purpose of the research, context of the activities, and age range of the participants to determine the content of the semi-structured interviews and formed three questions. Then, two experts evaluated these three questions based on the appropriateness for the purpose of the research, the context of the activities, and the age range of the participants. After the experts confirmed these questions, "What were the challenges you experienced when developing possible solutions", "What might be the reasons you go through these problems?", and "How was this experience for you?" were used in the final data collection. These interviews were conducted with the participants and each interview lasted approximately 20 min and took place in the classroom setting.

Data analysis

In 1950 J.P Guilford published a revolutionary article named 'Creativity'. In this article he claimed that the creativity was essential yet understudied field. He asserted following factors in creative talent; (a) fluency, the person who is capable of developing large number of ideas is more likely to develop significant ideas, (b) novelty, the person needs to produce uncommon responses to the items, (c) flexibility, the person needs to branch out into new channels of thought, (d) synthesizing/analysing ability, the person needs to break down the ideas so he/she can build new ones, (e) reorganization/redefinition, the person needs to transform an existing object into one of different design or function, (f) complexity, the person needs to manipulate a number of interrelated ideas at the same time, and finally (g) evaluation, the person needs to evaluate his/her ideas to select the good ones. Later on, in 1967 he built on his previous work and suggested that creative thinking needs to involve the roles of fluency, flexibility, and elaboration categorized these factors under the names of fluency, flexibility, originality, and elaboration (Guilford 1967a, b). In this study, researcher examined Guilford's (1950, 1967b) concepts of creative thinking in the data sources.

Field notes, semi-structured interviews with students, and students' writings were used as data sources. The data were analysed in two parts using descriptive and content analyses (Strauss and Corbin 1994). In the first part, the students' writings and drawings were examined using descriptive analysis. Based on the literature, creative problem solving needs to occur in an environment where students can offer more than one solution (fluency), different types of solutions (flexibility), unique and original solutions (originality), and need to elaborate on their solutions (detailedness). Therefore, the researchers examined the writings of students based on how many solutions they wrote, how varied and different solutions they offered, how much detail they presented in their solutions, and how often their solutions were offered by other groups using descriptive analysis. Each of the students' solutions were awarded with 1 point for fluency. For flexibility however, these solutions were analysed and only the ones that were different from the previous solution and that were not solely built upon the previous solution were awarded with 1 point. For the score of originality, the researchers cross examined all groups' solutions, compared each solution with the solutions of other groups and each solution that was unique in the entire sample was awarded with 1 point. And for the score of elaboration, the researchers gave 1 point to each solution that was explained in detail and helped the readers to visualize the final product in their minds. In Table 2, the researchers presented two of the students' writings and drawings, and their way of scoring these solutions.

In the second part, content analysis was used to analyse the field notes, and semi-structured interviews to corroborate the findings of descriptive analysis. Deductive method was used when analysing the semi-structured interview data. The researchers first examined the data and revealed the pattern of codes, then named the codes. They created the three themes named challenges, reasons, and experiences that cover these codes (Table 3). Finally, they associated each of these codes with the concepts of creativity based their contribution to the concepts of creativity.

Validity and reliability of research

Internal validity was first ensured by triangulation which is simply defined as the use of mix data or methods so that diverse viewpoints can clarify a topic (Creswell 2012). Therefore, in this research various data sources including students' writings, researchers' field notes, and semi-structured interviews were used for data collection. Also, for data analysis content analysis and descriptive analysis were applied to ensure the triangulation. Second, member checks (the researchers checked parts of the field and observation notes with participants to confirm that the interpretations were correct) were used for internal validity. Finally peer/college examination (asked two colleagues to check the credibility of the findings) was used to contribute internal validity (Merriam 1998). For the reliability of this research, the triangulation and peer examination were also used as well as the method of audit trail in which the researchers recorded every step in writing so that other researchers can follow the same steps if they would like to replicate the study (Merriam 1998).

Researchers' roles and ethical consideration

In this research, the researchers played two different roles. In the project, they played an emic role. They were more of insiders than outsiders because this research was conducted

Table 3 The frequency of creativity concepts in students' possible solutions based on groups in each activity

Activities	Groups	Fluency (f)	Flexibility (f)	Originality (f)	Elaboration (f)
1st activity helping people with visual disabilities in traffic	Eagles	9	5	2	8
	Canaries	11	6	0	8
	Lions	10	7	2	6
	Bears	8	5	0	7
	Monkeys	7	4	0	4
	Whales	7	6	1	7
2nd activity don't let cats and dogs dehydrate	Eagles	6	6	0	5
	Canaries	6	5	0	4
	Lions	9	5	0	6
	Bears	9	7	0	4
	Monkeys	10	6	0	10
	Whales	10	7	0	5
3rd activity an environment for birds to live in	Eagles	4	1	0	0
	Canaries	4	2	1	3
	Lions	3	2	0	2
	Bears	4	2	0	2
	Monkeys	5	2	1	3
	Whales	3	2	1	2

as part of a bigger project and in this project the researchers worked as instructors when activities took place. However, they played an etic role and were more of outsiders when collecting the data (Punch 1998). They did not intervene any of the students' designs. They only observed the students when the students created the designs and only asked questions to better understand the designs. Because the researchers played an etic role when collecting the data of this research, the researchers' roles were defined as outsiders for the purpose of this study.

The researchers took some precautions to ensure that the ethical rules were followed when conducting the research. To guarantee that the students were not physically harmed, the researchers and a nurse were present at all times in the learning environments that the activities took place. Also, the activities were reviewed by two different researchers and an ethics review board to ensure that the activities were appropriate for the selected age groups, and did not involve any material or statement that might physically or emotionally harm the students. Finally, the identities of the students were not revealed under any circumstances to the third parties, and to ensure the confidentiality of the children the students' faces were blurred in the photos used in this manuscript were blurred.

Results of research

The purpose of this research was to examine the concepts of creativity demonstrated in the developing possible solutions step of the DBL. The results were organized based on the research questions and presented under the sub-headings creativity concepts in students' possible solutions and creativity concepts based on students' perceptions.

Creativity concepts in students' possible solutions

The frequency of creativity concepts including fluency, flexibility, originality, and elaboration demonstrated in students' possible solutions were presented in Table 3.

In Table 3, the scores in each column represented how many ideas of the groups' were categorized (frequency of the ideas) under each concept of the creativity for each activity. As described in the method section fluency refers to the number of correct ideas, solutions, or answers. For example for the first design challenge named Helping people with visual disabilities in traffic, the students in the Eagles Group produced nine ideas counted in the fluency category. Flexibility refers to the number of different categories of ideas, solutions, or answers. Out of the nine ideas presented under fluency, six of them were distinctively different from each other that counted for flexibility. Originality refers to uniqueness or statistical infrequency of the ideas, solutions, or answers. Two of these ideas were never asserted by other groups, therefore considered to be unique and counted for originality. Elaboration refers to the richness and detailedness of the content. Eight of these ideas were elaborately defined so each of these ideas was easily understood without needing any further explanation. Compared to the first activity, the students developed fewer solutions in the second design challenge. However, when flexibility concept was taken into consideration, all of the solutions that the participants developed were distinctively different from each other. Therefore, the frequency of the flexibility of the solutions in the second design challenge was higher than the flexibility of the solutions developed for the first design challenge. For the originality concept, all of the solutions were offered by the other groups and none of the solutions were unique to this group. All of the solutions were elaborately defined except one. For the third design challenge, all of the scores for creativity concepts were lower than the first two design challenges.

For the Canaries Group, the frequency of the fluency of the ideas decreased from first to last design challenge. The frequency of the flexibility of the ideas might seem to be decreased from first to last design challenge. Only in the third design challenge, the students were able to offer a unique solution. Finally, in all three design challenges the students elaborately described their ideas with few exceptions. For the Lions Group, the frequency of the fluency of the solutions decreased from first to the last design challenge. The students produced original solutions only for the first design challenge. Finally, in all three design challenges the students elaborately described their ideas with few exceptions. For the Bears Group, the students developed more solutions in the first two design challenges compared to the third design challenge. None of the solutions was unique to this group. Finally considering the elaboration concepts of creativity, the students explained more solutions in detail in the first design challenge. The frequency of the fluency, flexibility, and elaboration of the solutions were higher for the second design challenge for the Monkeys group. However, the students were able to develop an original solution for only the third design challenge. For the Whales group, the frequency of the fluency of the solutions was higher for the second design challenge. The frequency of the flexibility of the solutions was similar for all three design challenges. They developed original solutions for the first and last design challenge. In addition, all of the solutions were elaborately described in the first design challenge. After examining all the concepts based on each group, the researchers also analysed all the solutions regardless of the groups. The results were presented in Table 4.

When all the groups' solutions were taken into consideration across all three design challenges, the frequency of the fluency of the solutions developed for the first two design challenges were almost the same. However, the students developed considerably fewer solutions for the third design challenge. The students did not develop original solutions in the second design challenge, and the frequency of the original solutions was considerably low comparing the number of solutions and different solutions they developed for the first and last design challenge.

Above, the data obtained from students' drawings were descriptively analysed considering frequency of the concepts of the creativity in students' drawings. In order to provide a better picture of the problem, the data obtained from the semi-structured interviews and field notes were also analysed.

Table 4 Creativity concepts in students' possible solutions in total

Concepts of creativity	1st activity: helping people with visual disabilities in traffic	2nd activity: don't let cats and dogs dehydrate	3rd activity: an environment for birds to live in
Fluency	35	36	18
Flexibility	21	15	11
Originality	5	0	3
Elaboration	28	26	10

Fig. 1 Choosing the best solution (activity 1)

Fig. 2 Making a prototype (activity 2)

Fig. 3 Making a prototype in nature (activity 3)

Creativity concepts based on students' perceptions

After the students were divided into six randomly assigned groups, the researchers started observing the students and taking field notes. The researchers continued to take field notes during the entire DBL process. At the end of each day, the researchers compared their field notes. Both researchers agreed on several issues in their notes. The photos of students' work environments were provided below to help the readers grasp the concept of DBL learning environment (Figs. 1, 2, 3).

The field notes regarding the fluency component included the observations regarding the ability to produce a number of solutions. Most of the students were observed to be reluctant to write down more than one or two solutions. Some students especially asked if one solution would be enough. To avoid intervening the process and to help the students keep an open mind, the researchers continued to provide the same response, "However, you want" for these types of questions. However, it has been observed that students experienced some problems when generating more than one or two ideas which reflected to the frequency of fluency.

The field notes regarding the flexibility component of creativity included the observations of different categories of solutions students developed. The most noticeable behaviour among the students was that even if the researchers took all the necessary measures to stop students sharing their ideas and affecting each other, once a student stated his/her idea out loud, all of the other students in the group started generating ideas based on the loudly stated idea. This was one of the major handicaps for building flexibility. Even if no student declared his/her idea out loud, most of the students followed the same strategy when generating ideas, that was once they came up with an idea, the rest of ideas were built upon the first one.

The notes regarding the originality component included observations of students developing solutions that have never been mentioned, used, or developed by any other group or individual during the project. Stating the ideas out loud and developing solutions based on the previously developed ideas can affect each other's thinking process and block other students' ability to come up with unique ideas. Therefore, all the above-mentioned points that seemed to affect flexibility can also be listed among the reasons that have an impact on the originality component of creativity as well.

The field notes regarding the elaboration component included detailed descriptions of students' solutions. Most of the students were observed to present their ideas by only using the drawings and very little text if not at all accompanying their drawing in the first activity. These students asked the researchers if the drawings were enough on their own. The researchers used the same generated response, "however you want" to help the students keep an open mind. After the first activity, the students were observed to provide more elaborated solutions for the second and third activity.

The researchers observed students across all three design challenges as well. In the first two design challenges, the students seemed to be engaged in the DBL process. However, especially in the third design challenge, the researchers agreed on their field notes that the students seemed highly distracted by what they encountered in nature. The researchers had to draw students' attention to the design challenge with oral warnings more than two times. Therefore, all four of the creativity concepts including fluency, flexibility, originality, and elaboration were affected when the activity was carried out in nature.

Along with the field notes the researchers also conducted semi-structured short time interviews with all twenty four students. The researchers asked questions to students and based on the responses; the researchers directed more questions to clarify which could be considered as the semi structured interview process. The three questions in these interviews were "What were the challenges you experienced when developing possible solutions?", "What might be the reasons you go through these problems?", and "How was this

Table 5 Findings of the semi-structured interviews

Themes	Codes	Related component	Frequency
Challenges	Generating solutions	Fluency, flexibility	21
	Making prototypes	Originality	21
Reasons	Similarity	Flexibility, originality	20
	Familiarity	Fluency	10
	Boredom	Fluency, elaboration	3
Experiences	Team work	–	22
	More ideas	Fluency	21
	Solving real problems	–	17
	Original ideas	Originality	13
	Detailed ideas	Elaboration	4

experience for you?" Then, the researchers used deductive analysis as they treated each question as a theme (broader category) and coded the answers of the students under each theme. Then, the researchers added the related creativity concepts in each line to demonstrate which code had an impact on which concept. The themes and codes derived from the semi-structured interviews as well as the frequency of these codes and related components of creativity were presented in Table 5.

Each question in the semi-structured interview was treated as a theme. Therefore, three different themes were formed. In the first theme, challenges, 2 different codes were generated based on the students' answers. The first code, generating solutions, was used to describe the situation that it was difficult for 21 students to develop more than one solution. Students stated that once they came up with one solution, it was really difficult for them to think of another idea that was completely different from the first one. One of the students stated that "I understand the problem, however I only can think of one solution. It has been difficult for me to think of any other way to solve the problem" (S21). Another one expressed her thoughts as "I think it was not easy to develop many solutions, I had to think a lot" (S18). Therefore, the challenges students experienced when developing more solutions affected both the number of developed solutions (fluency) and the number of different categories of solutions (flexibility). The second code, making prototypes, was used to describe the phenomenon that 21 students expressed that knowing that they would actually have to make a working prototype of their solutions prevented them to come up with unique ideas. Because they eventually needed to build up a model, they only focused on coming up with a solution that could be easily made rather than being unique (originality). One of the students stated that "I kept thinking how I was going to make a working prototype of my design. It was difficult for me to make a model of my solution" (S15). Another one's exact statement was "We developed a lot of solutions and chose the best. However, when it came to actually making it, we had a hard time making the exact model as we designed" (S7).

In the second theme, reasons, 3 different codes were generated. The first code, similarity, was generated to describe that 20 students expressed that the ideas and the solutions they came up were similar and not very different than each other which affected both the number of different categories of solutions (flexibility) and the uniqueness of solutions (originality). One of the students in this category stated that "Our solutions were just too similar to each other" (S11). *Another statement was* "For example, when we got together with our group mates, I realized we just wandered around the same solutions*" (S8).* The second code familiarity was generated for the students' expressions regarding their familiarity of these types of activities. Ten of the students specifically stated that they were not used to these types of activities and therefore they could not generate more solutions than one or two which in turn affected the fluency component. One of the students in this category specifically stated that "It is not like school here. We also tried to solve problems at school, however it was enough to solve the problem in one way. If you got it right, then you got it right. Here, on the other hand, you asked as to find too many solutions. This feels good but somehow different" (S9). The third code, boredom, was used to define three students who said that they were bored and not willing to develop solutions and explain those solutions in detail which also affected fluency and elaboration. One student's statement would be helpful to clarify the reasons theme as S5 answered to this question as "Because I have never done this type of activity, it was hard for me to think of more than one solution. Once I came up with one solution, I thought this should be enough, I solved the problem anyway which was all that matters. It bored me to try to think of more solutions when I already solved it in one way".

Five different codes were generated under the last theme, experiences. The first code, team work, was used to describe 22 students who mentioned that the DBL activities helped them work collaboratively. The second code, more ideas was created to define students' answers that it was important to develop more ideas (fluency) to be able to reach the best solution. Solving real problems, the third code was generated to cover the students' statements ($f=17$) that solving the problems with real life context actually engaged them in the problem solving process. The final two codes, original and detailed ideas were about uniqueness (originality) ($f=13$) and detailedness (elaboration) ($f=4$) of the ideas. The students stated that they needed to come up with original ideas and elaborate on those ideas to be able to reach the best solution. Based on the results obtained from the analyses of the semi-structured interviews, it has been concluded that the data from semi-structured interviews supported the findings from the field notes. Some of the statements of students were as follows; "First of all, the biggest contribution was to be able to think more than one way to solve a problem. I also understood the importance of the group work. While we worked together, I realized that I had to write down and describe my solutions more clearly and in detail so that they could clearly understand what I actually meant with my drawings" (S22). "I realized that group work was really important because what we produced at the end with the combined ideas was better than what each of us designed in the beginning. We just took the best part of each solution when made our prototypes" (S7). "It was important to think differently to find the best solution" (S17).

Discussion, conclusion, and implications

In this study, the researchers sought to answer the research questions of to what extent students demonstrated creativity when developing possible solutions in DBL and what the students perceptions were of the DBL. Based on the findings of this study, the highest frequency was obtained in the fluency concept of creativity, followed by elaboration, flexibility, and originality in that order in developing possible solutions step of DBL. Although fluency has the highest frequency in students' possible solutions, it is not enough to derive a sound conclusion about students' creativity based on only the frequency of fluency. Since, creativity has three more concepts including flexibility, originality, and elaboration, it is important for students to demonstrate high frequency in all four concepts to be able to recognize as creative persons (Guilford 1967a, b; Kaufman et al. 2008; Leikin et al. 2009; Torrance 1974). When examining the reasons for low frequency in other three concepts than fluency, the researchers revealed from students' statements that it was difficult for them to develop different solutions once they came up with the correct solution which affected the flexibility and originality concepts. This finding can be explained by the nature of developing possible solutions step of DBL (Brunsell 2012; Mentzer 2011). In this step, students were asked to develop as much solutions as possible for design challenge to select the best solution for making a prototype which align with the fluency concept of creativity. Based on our findings it was evident that the fluency scores were similar for the first two activities. However, in terms of flexibility and originality, the frequency decreased from first to second activity. Because students were aware that they were expected to develop a number of solutions in the first two activities, their fluency scores were high. On the other hand, by the third activity because they grasped the concept of making a design better, their process of developing solutions headed towards developing solutions that were easy to convert into a prototype. In other words, in the first two activities, their focus was on the quantity of the solutions while in the third one, the focus shifted towards the feasibility of the solution. Therefore, by the third activity the students learned that they only needed to develop a few solutions that could be turned into a prototype, so they stopped developing more solutions and focused on developing an effective solution for the prototype. This finding was consistent with the studies of Syukri et al. (2017) in which originality was found to have the lowest mean score among all creativity concepts and of Mayasari et al. (2016) in which the scores of fluency and flexibility were similar to each other and higher than the originality and elaboration.

Another reason for students to receive low scores in originality might be that most of these activities were carried on in a small classroom setting. In this classroom students were located within a close range of each other. Therefore, although the researchers took some measures for students not to hear each other's immature thoughts, because it was a small classroom setting, when one group or student proposed a solution to a problem out loud, other students could easily hear this premature thought and be affected by these thoughts. This finding is consistent with the study of Jindal-Snape et al. (2013) stating that the physical structure of a classroom had an impact on students' ability to demonstrate creativity.

And as stated in the field notes of both researchers, once a group or a student planted a solution in other students' minds by stating it out loud, the rest of the students usually blocked themselves to think about any other original ideas. This either might be because of the fear that the students had for receiving critiques about their original thoughts or brainstorming actually yielded to a degree of production loss (Runco 2014; Kowaltowski et al. 2010). Because of these reasons, students only developed the solutions based on the first stated one and stopped generating new solutions after that. Therefore, when DBL is implemented in educational settings, the students should be placed in an educational setting in which they are placed as far from each other as possible and minimum interaction with each other should be ensured when developing possible solutions, so that the possibility of affecting each other's ideas can be decreased.

As for the elaboration, the students were able to provide detailed explanations for their solutions. When the researchers revisited their field notes to explain these findings, they were able to provide some explanations. They believe that because the students were selected from the pool of students with high grade point equivalents, students had enough knowledge to elaborate on their solutions which reflected on their elaboration scores. They also believe that another explanation of the high elaboration scores would be that the students were aware that the group would need to select the best solution among the provided solutions, so each student need to elaborate on their own solutions to present the solutions to their groups.

We answered the second research question regarding the perceptions that students experienced when developing possible solutions in DBL by using the semi-structured interviews and field notes. The students stated that the biggest challenges in the process were generating solutions and making prototypes in the first theme of semi-structured interviews. This finding might be best explained by their lack of experience in these types of activities in general education classrooms. In general education classrooms, students are encouraged to have high grades in especially science and mathematics classes and it is usually enough to offer one correct solution to a problem to receive a high grade from the class. In other words, in regular classroom settings students have been encouraged to offer one correct solution rather than developing various and original solutions. Therefore, students were not used to generate different solutions and putting those solutions into use. Because, they have problems developing more than one or two solutions and they keep producing the same ideas with slight differences, they also have problems developing different types of solutions which in turn affected the fluency, flexibility, and originality concepts of creativity. This finding was consistent with Chin's finding (1997) that if the emphasis is only on the correct solution, originality and creativity of the students can be diminished. Considering, creativity is one of the required skills to survive in twentyfirst century, teachers in general education classrooms should plan their lessons to motivate students develop both correct and original solutions. In the creativity-centred classroom, K-12 students learn to identify and solve open-ended problems (Parkhurst 1999), apply independent thinking (Cropley 1997), and they are motivated to create, invent, discover, explore, imagine, and suppose (Sternberg 2003). Therefore, one way of building a creativity-centred classroom could be to use DBL in regular education classrooms as an instructional method. The results of the study of Syukri et al. (2017) also supported the claim that learning physics that integrated five steps of engineering design was more effective in developing students' creativity skills compared to the traditional method of teaching and learning physics.

The findings of the second theme of the semi structured interview also supported this explanation. In this theme, students' statements regarding developing similar solutions, not being familiar to this type of design making process and being bored supported the findings derived from field notes. Finally, students' expressions for the experiences including team work, more ideas, solving real problems, original ideas, and detailed ideas would reveal the fact that DBL process contributed these students in these areas and affected students creativity in the concepts of fluency, originality, and elaboration. Several researchers also pointed out that students' creativity might increase during DBL process (Chasanah et al. 2017; Hathcock et al. 2015; Lasky and Yoon 2011; Mayasari et al. 2016; Rosa 2016; Siew 2017; Syukri et al. 2017). Considering DBL as a way of implementing STEM education, the literature stating that the STEM education developed creativity (Biçer et al. 2017; Harris and Bruin 2018; Henriksen 2014; Nemiro et al. 2017) supported the findings of this study.

When replicating the current study, future researchers should consider several implications drawn from this study. First of all, when selecting the design challenges, the researchers need to ensure the appropriateness of the educational setting to promote creative thinking of the students. For example, portable desks might be helpful to create such learning environment. During the individual work time, the students might seat apart from each other to not to have dialogues with each other about their solutions and not to get influenced by other students' ideas, and later during group work time the desks might be brought together to allow students work with groups. Also, the teachers should make some rules with students for individual and group work. The teacher should clearly justify the rule of no communication during individual work so that the students have no hesitation following this rule when they are working alone. The teacher should remind the students that once they get together with their group mates, they will discuss the solutions they developed. Second, to not to intervene the process, the researchers used a generic answer for students' all questions. However, to examine the change in the creativity concepts in DBL process, future researchers might try to encourage students to develop as many solutions as possible as well as developing original solutions with detailed descriptions. In the literature the researchers found that the creativity concepts in participants' products improved in each concept respectively after 15 lessons of design learning (Chasanah et al. 2017; Mayasari et al. 2016; Syukri et al. 2017). Therefore, the students might be expected to demonstrated high levels of creativity concepts after an instructional process. Third, the use of DBL should be consistent with the general education curriculum so that the students become familiar with these types of educational activities. Fourth, although this study can be considered as an indication of the fact that STEM projects might be implemented as a way of developing creativity, longitudinal research designs would be more suitable to support the literature suggesting that engineering design process can be applied as a means for fostering creativity, problem solving skills, and thinking skills (Siew 2017). Also, the longitudinal designs would allow future researchers to compare the project and problem types and the effects of different types of projects on creativity concepts.

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