Goktepe-Yildiz, S., Ozdemir, A.S. (2021). The effects of engineering design-based mathematics applications on spatial abilities and 3d geometrical thinking skills of students with different learning approaches. *International Online Journal of Education and Teaching (IOJET), 8*(2). 932-959.

Received : 27.07.2020
Revised version received : 30.11.2020
Accepted : 12.12.2020

THE EFFECTS OF ENGINEERING DESIGN-BASED MATHEMATICS APPLICATIONS ON SPATIAL ABILITIES AND 3D GEOMETRICAL THINKING SKILLS OF STUDENTS WITH DIFFERENT LEARNING APPROACHES

Research article

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THE EFFECTS OF ENGINEERING DESIGN-BASED MATHEMATICS APPLICATIONS ON SPATIAL ABILITIES AND 3D GEOMETRICAL THINKING SKILLS OF STUDENTS WITH DIFFERENT LEARNING APPROACHES[1]

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Abstract

Design activities help students develop their three-dimensional thinking skills and gain engineering and technology literacy. This study investigated whether the spatial abilities and 3D geometrical thinking skills of the students differed according to approaches to learning mathematics before and after engineering design-based mathematics (EDBM) applications. Seventy-five eighth-grade students from a public middle school participated in the study. Data were collected with 3D Geometrical Thinking Test (3DGTT), Spatial Ability Test (SAT) and Approaches to Learning Mathematics Scale (ALMS). In the research, quasi-experimental design with pre-test and post-test control group was used. Engineering design-based mathematics activities were carried out an eight-week period, while the control group received mathematics instruction in line with traditional teaching methods. The results of the study showed that the spatial abilities of the students differed according to the approaches to learning mathematics, whereas the 3D geometrical thinking skills of the students did not differ.

Keywords: Engineering design-based mathematics (EDBM) activities**,** approaches to learning mathematics, spatial ability, 3 dimensional geometrical thinking skills

1. Introduction

Brophy and colleagues (2008) state that teaching mathematics and science by using design-based learning which is based on questioning, improve students spatial reasoning abilities. Design activities help students gain three-dimensional thinking abilities and literacy of engineering and technology (Cunningham et al., 2007). Given that most of the studies emphasize the importance of improving students' spatial abilities in three-dimensional geometry teaching (Clements & Sarama, 2007; Presmeg, 2006); it is necessary to provide students with successful engineering design-based activities. Engineering design-based learning, which can be considered as a special area of design-based learning, is crucial especially in middle school level because it has the potential to develop students' self-sufficiency and prompt them understanding the process of engineering design procedure (Carr, Bennett & Strobel, 2012). However, traditional classroom environments generally lack designing activities and they do not prepare students to solve real-life problems (Moreno et al., 2016). Several studies reveal that traditional teaching activities may cause to memorize the true knowledge and do not provide meaningful learning (Loverude, Kautz & Heron, 2002). Meaningful learning occurs when learners make a connection between their former knowledge

[1] This study was produced from the first author's doctoral dissertation and was supported by Marmara University as a BAP project with the number EGT-C-DRP-091215-0543.

and new experiences in a real-life context (Brooks & Brooks, 1993). Meaningful learning is matching up with deep learning approach (Offir, Lev & Bezalel, 2008) and surface learning approach, that is cohering with rote learning are generally learning, approaches of students (Marton & Saljo, 1976). When looked through with the dilemma of meaningful learning and rote learning, learning approaches of students integrates into this research.

Integrating design-based applications into the teaching process provides opportunities for students to adopt deep approach. This develops students' problem solving and critical thinking abilities and at the same time, improves their creativity (Purzer & Shelley, 2018). Engineering integration, provide students with more meaningful learning experiences by combining students' individual and real-life experiences with the information of other disciplines (Capraro & Slough, 2008). However, most research on engineering design focuses on high school and senior students, with smaller grades being limited (English & King, 2015). This is partly due to the view that design processes are too complex for small classes. As much of the research is aimed at older students, there is a need for studies in which younger students use engineering design processes. As stated in the studies, the middle school period is the period that has the most impact on students' lives compared to other times. Besides, these years are the years when students think about their future career and academic life (Singh, Granville & Dika, 2002). Based on this information, this research was conducted with 8^{th} grade students, which is the last stage before transitioning to one of the important decision-making stages of their educational life, and engineering design-based activities were carried out. Hence, the research and the findings obtained at the end of the research important.The research questions are as follows:

(1) Do the spatial abilities of the students according to the approaches to learning mathematics show any significant difference before and after the EDBM activities?

(2) Do the 3D geometrical thinking skills of the students according to the approaches to learning mathematics show any significant difference before and after the EDBM activities?

1.1. Spatial Ability

When looking at educational psychology research, it is often seen that a distinction is made between "spatial ability" and "spatial skill". Spatial ability is the innate visualization ability that a person has before any formal education, that is, the individual is born with some abilities. Spatial skill is learned and can be acquired through training (Sorby, 1999). Some people may have higher degrees of innate abilities than others may (as is the case with other skills such as writing and mathematics). However, most people can develop this skill through patience and working (Sorby et al., 2003). While spatial ability was previously considered an innate ability (Samsudin, Rafi & Hanif, 2011), the evidence obtained from experimental studies shows that significant improvements are possible with a correct and specific education (Turos & Ervin, 2000). In addition, spatial ability begins to develop from infancy as the individual interacts with the environment. With the advancement of age, it develops in connection with intelligence (Newcombe & Huttenlocher, 2000). It is almost impossible to distinguish between the spatial abilities and spatial skills of middle school students because we do not have information about the teaching activities or their non-participation in teaching activities before reaching this education level, and it is still a matter of debate whether this phenomenon is a ability or a skill (Turğut, 2007). For this reason, the terms "spatial ability" and "spatial skill" are used interchangeably in this study. In addition, when the educational literature is examined, concepts such as spatial thinking, spatial reasoning, and spatial perception are used instead of spatial ability (Clements & Battista, 1992; Olkun, 2003). It can be said that this difference stems from the situation of looking at spatial ability from different perspectives.

Spatial ability has been one of the important fields for educational psychology since the 1920s and 1930s. However, unlike other types of ability, there is no real consensus on what the term spatial ability means (Sorby, 1999). Ekstrom, French, Harman, and Dermen (1976) defined spatial ability as the ability to comprehend spatial shapes and to understand the orientation in new situations in space. McGee (1979) expressed spatial ability as the ability to formulate mental images and to manipulate these images in the mind. According to Linn and Petersen (1985), spatial ability means "the ability to represent, transform, produce and remember symbolic, non-linguistic information" (p.1482). Linn and Petersen (1985) stated that spatial ability is not a single structure, but a combination of sub-skills such as using maps, solving geometry questions, and recognizing two-dimensional representation of three-dimensional objects. According to Tarte (1990), spatial ability is the ability to visually understand and use the relationships between objects, to rearrange and express them. Carroll (1993) defined spatial ability as a combination of imagination, perception, interpretation, and understanding of visual relations of objects. Lohman (1996) defined spatial skill as the ability to create, transform and remember well-structured images. Stockdale and Possion (1998) discussed this ability in more detail and stated that spatial ability is the ability of an individual to establish spatial relationships between himself and his environment. He included properties such as distance, size, volume, and time into spatial relationships. According to Olkun (2003), spatial ability includes information about the use of the geometric form of space. The researcher expressed the spatial ability as the ability to create, rotate, and interpret two and three-dimensional parts of objects in the mind. Turğut (2007) as the ability to visualize and move objects and components made up of one or more parts in three-dimensional space defined spatial ability. Considering the definitions about spatial ability, in general above; spatial ability is defined as a combination of skills such as moving objects mentally, integrating and fragmenting objects in the mind, or visualizing objects from a different perspective (Turgut, 2015).

Salisbury (1987) defines geometry as recognizing and moving three-dimensional shapes from two-dimensional shapes, similar to the definitions for spatial ability. In this study, two interrelated skills, spatial ability and three-dimensional geometrical thinking skill (Clements & Sarama, 2007; Gutierrez, 1992) were discussed separately. Under the following title, 3-dimensional geometrical thinking skills were mentioned.

The National Mathematics Teachers Council (NCTM) (2000) proposes to integrate spatial reasoning into the elementary mathematics curriculum. In addition, many people now believe that spatial education can be an important resource for improving performance in science, technology, engineering and mathematics (STEM) disciplines (Lubinski, 2010; Newcombe, 2010). Toys, sports, computer games and different course options related to spatial ability (Cherney & London, 2006) contribute to spatial experiences of children (Cherney, 2008). Literature meta-analyzes the development of spatial ability show (Baenninger & Newcombe, 1989; Uttal, 2009): 1) participation in spatial activities such as sports, crafts and other hobbies is positively associated with spatial ability scores, and 2) spatial ability performance can be improved through training. On the other hand, Sorby (2007) listed the activities that improve spatial ability as follows: 1) playing with toys (e.g., Lego) in early childhood, 2) participating in technical drawing and mechanics in middle school or high school, 3) playing 3D computer games, 4) participating in certain types of sports and 5) participating in activities with well-developed mathematics skills. In this study, in line with the types of activities that improve spatial ability specified by Sorby (1999), engineering design-based mathematical (EDBM) activities were carried out under three headings: 1) mathematical applications with concrete materials, 2) computer-aided mathematics applications and 3) free mathematics applications.

1.2. 3D geometrical thinking skills

Mathematics education research emphasizes the role of visualization processes in 3D geometrical thinking (Presmeg, 2006). Similarly, Owens and Barraclough (2001) used the term spatial thinking about three-dimensional objects for three-dimensional thinking. Studies on 3-dimensional geometry generally focus on the abilities of students in this area and the tasks directly included in the school curriculum (Gutierrez, Lawrie & Pegg, 2004). These abilities include the transformation of different representations of 3-dimensional objects, the definition and creation of expansions, spatial structuring of cube arrays, the definition of 3-dimensional solids and their elements, the calculation of the surface area and volume of 3-dimensional objects, and the recognition of geometric objects in space (NCTM, 2000).

In order to explain the structure of 3D geometry thinking, various types of reasoning related to 3-dimensional geometry concepts were brought together and 3-dimensional geometry reasoning types were proposed. Here, the concept of "reasoning" refers to a set of processes and abilities that serve as a viable tool in problem solving and enable us to go beyond the information provided (Pittalis & Christou, 2010). In this study, it is accepted that the types of reasoning defined in 3-dimensional geometry and spatial abilities are modeled as different structures, and based on the literature, four types of reasoning skills determined by Pittalis and Christou (2010) in 3-dimensional geometric thinking are discussed. The first type of reasoning implies representations of 3-dimensional objects; the second type of reasoning is related to spatial structuring, the third to the conceptualization of mathematical properties, and the fourth to measurement in 3-dimensional geometry.

Engineering design activities can help students develop their three-dimensional thinking skills and gain engineering and technology literacy skills (Cunningham et al., 2007). There are studies that have reached the conclusion that three modules used in this research improve the 3-dimensional geometric thinking of students. As a result of the studies of Olkun and Sinoplu (2008), Topbaş Tat and Bulut (2009), it has been shown that concrete material supported applications can be effective on the development of students' 3-dimensional geometrical reasoning. McClurg et al. (1997), Christou et al. (2007) and Lin et al. (2011) concluded that computer-aided applications are effective on the development of students' 3-dimensional geometrical reasoning. In addition, engineering design can be used concretely in applications for mathematics and science concepts and in solving problems in these areas (Miaoulis, 2014).

1.3. Engineering design-based activities

With a focus on design and problem solving, engineering is used in K-12 education to encourage learning in STEM fields (science, technology, engineering, and mathematics). However, historically engineering in educational research has received little attention as part of the core issues in the K-12 education system. However, engineering is no longer considered a forgotten component of the K-12 STEM (science, technology, engineering and mathematics) package, but largely as an integrative component (Purzer & Shelley, 2018). Engineering requires the use of scientific and mathematical concepts to address the types of well-structured and open-ended problems that occur in the real world (Sheppard et al., 2009). In this study, since engineering integration into the mathematics lesson is carried out with engineering design activities using the engineering design process, the activities in the research are named as "design based mathematics applications".

Marulcu (2010) emphasizes the common points of Design by Learning™ Kolodner (2006), design-based modeling (Penner et al., 1998) and engineering for children (Roth, 1996) to make a clear definition of engineering design. It is based on these three definitions. Engineering design is an activity that involves the construction of a physical product that solves human problems (Marulcu, 2010).

Being involved in engineering design motivates students, encourages critical thinking, and provides opportunities for the application of science and mathematical concepts (Ganesh & Schnittka, 2014). Brophy et al. (2008) listed how inquiry-based science and mathematics teaching using engineering design-based teaching can improve students' competencies as follows:

• Developing cognitive models about how systems work,

• Sharing and negotiating ideas with others,

• Using geometric and spatial reasoning,

• Showing and managing the complexity of a system using diagrams,

• Expressing ideas and results with mathematics (calculations, tables, graphs, charts),

• Properly synthesizing ideas for a solution that meets the goals,

• Evaluating whether a design meets success criteria

Primary-middle school students begin to undertake and implement applications similar to real-world engineers, so it is important to examine how students in these age groups are involved in the engineering design process (Brown, 2017). Including students in authentic engineering contexts gives them the opportunity to learn by experiencing how engineers solve problems, work in teams, and use science and mathematics (Capobianco, Yu & French, 2014). Based on the results of Alemdar et al. (2018) research, it is stated that students can significantly benefit both their academic achievement in science and mathematics classes and their participation in STEM by participating in engineering activities at middle school level.

In engineering design-based learning, the activity that aims to encourage learning is a design project. Students are required to use and extend their knowledge of science and mathematics to develop a technological solution to a problem using available resources. In this study, students carried out engineering design-based mathematics (EDBM) activities by using their mathematical knowledge and employing their spatial abilities and 3D thinking skills.

1.4. Approaches to learning

Engineering integration, provide students with more meaningful learning experiences by combining students' individual and real-life experiences with the information of other disciplines (Capraro & Slough, 2008). When mathematics lessons are performed in traditional teaching methods, students have to struggle with definitions and formulas, also they have difficulty in learning basic mathematical concepts and do not know how to use them in problem solving. Traditional classroom environments, where evaluation methods are based on memorization, compel students to prefer a surface learning approach (Spencer, 2003). Integrating design-based applications to the teaching process provide students opportunities for adopting a deep approach. It enhances creativity, problem solving and critical thinking abilities of students (Purzer & Shelley, 2018). On the basis of the importance of learning approaches in the educational experiences of students, it is crucial to determine the students' preferences of learning mathematics and prepare the learning environment according to these preferences while they are at secondary school and on the eve of making important decisions like job selection, which actually occur at high school and university levels. Besides, along with being accepted as individual difference, learning approaches are not stable (Demirel, 2000). Therefore, teaching activities affect directly the approaches of students during a lesson (Selçuk, 2013). According to this, it is important for mathematics teachers to take the learning approaches of students into consideration before getting into teaching activities. In this study, students' approaches to learning mathematics were examined in three dimensions: deep, superficial and strategic.

Students, who learn deeply, make a connection with the new information they learn and their former knowledge and make inferences from the information they just learn (Offir, Lev & Bezalel, 2008). They examine the product they acquire from a critical aspect, actively take part in the activities that are related topic they are about to learn (Beydoğan, 2007). In the surface learning approach, on the other hand, there focus on memorizing without taking the relationship of one information with the other into consideration (Trigwell & Prosser, 1991). Because of the structure of mathematics, it is crucial to make connections in the lesson and out of the lesson (Ersoy, 2006). During the mathematics lessons, sometimes there may be upper-level information on some topics and students have to memorize some formulas and calculating patterns. It is not possible to give these argument formulas to the students. In this kind of situations, the strategic learning approach is applied. According to the strategic learning approach features, both associating event and memorizing at a partial level occur sometimes (Darlington, 2011). Strategic learners tend to learn by being affected by the environment, not by the nature of learning as opposed to deep learners (Newble & Entwistle, 1986). Students who adopt this approach are aware of the clues to enhance their academic success chances and evaluating criteria (Heikkila & Lonka, 2006); moreover, they know how will the evaluation be carried out and they can organize their time in a way that provides them to get the highest scores (McCune & Entwistle, 2000).

Research results show that students lose their interests in science, technology, engineering and mathematics (STEM) fields at the middle school level before they reach high school level yet (Marasco & Behjat, 2013). In fact, students go to school with a powerful interest in science but the decrease of their motivation stems from the way science is thought to them (Krajcik et al., 2003). This result coincides with the result that different variables in a teaching-learning environment (teaching methods, motivation, success, the attitude of the teacher to students, and etc.) affect students' learning approaches in a discipline (Rhem, 1995). Research results also state that the quality of the product that appears at the end of the process can be altered largely by organizing the learning environment (Entwistle & Tait, 1990; Biggs, 1999; Fry, Ketteridge & Marshall, 2003). Therefore, it can provide an efficient learning environment for mathematics teachers to perform teaching activities by considering students' learning approaches. Engineering design-based mathematics (EDBM) applications can be counted among the alternative learning activities from this aspect.

2. Methodology

Pre-test/post-test quasi-experimental design with a non-equivalent control group (Gay & Airasian, 2000) was used in the research. In quasi-experimental studies, experimental and control groups are determined randomly. Participants are largely composed of individuals with similar characteristics (Çepni, 2010). In the present study, two classes were selected as the experimental group and two classes were selected as the control group, which were previously indicated as having equal academic levels by the school administration. The experimental and control groups were equivalent in terms of spatial ability ($U=575.50$, $p>.05$) and 3-dimensional geometrical thinking skills ($F(1, 72) = 2.992$, $p>.05$) variables. In two groups, "Approaches to Learning Mathematics Scale (ALMS), Spatial Ability Test (SAT), 3D Geometrical Thinking Test (3DGTT)" pre-tests and post-tests were administered before and after the implementation.

2.1. Participants

The participants of this study consisted of seventy-five 8th grade students from a public school located in Beşiktaş, Istanbul. Because of the fact that it was difficult to implement the EDBM activities in crowded classes, the school was selected for having fewer students in the classes. At the same time, the ease of access to the school was another factor in choosing. The school had good physical facilities and a computer lab. Socio-economic level of students was slightly above average. The research was carried out as an elective course in Mathematics Applications course which has been taught in 5th, 6th, 7th and 8th grades since 2013-2014 for two hours each. All students in the experimental and control groups chose this lesson. The school administration and the teacher, who gave a lesson on mathematics practices to 8th grades, approached the EDBM application positively. The required permissions to carry out the research in the selected school were obtained from provincial directorate for national education. The research was conducted in the second semester of the 2015-2016 academic year. The reason for choosing eighth grade students was that they had developed mathematical terminology and abstract thinking skills up to this grade level. In addition, it was thought that the students were at a level to make a mathematical discussion and comment using the mathematical language. There were four 8th grade classes in the school: 8A, 8B, 8C and 8D. With simple random sampling, 8B (n=19) and 8D (n=16) classes were selected as experimental group while 8A (n=22) and 8C (n=18) classes were selected as control group. Totally 75 students participated in the research, 35 of them were included in the experimental group and 40 them were included in the control group. Detailed information about the participants was provided in Table 1.

Table 1. *Distribution of the participants by gender and group*

Participants	Experimental Group		Control Group	
	Female	Male	Female	Male
	17	18	18	22
Total	35		40	

When participants are analyzed according to their genders, it can be seen that 17 (50%) of the students are female in the experimental group while 18 (50%) of the students are male. On the other hand, 22 (55%) of the students in the control group are male and 18 (48%) are female.

2.2. Data Collection Tools

Three different data collection instruments were applied during the data collection process: Approaches to Learning Mathematics Scale (ALMS), Spatial Ability Test (SAT), 3D Geometrical Thinking Test (3DGTT). Detailed information about data collection tools was provided by under titles below.

2.2.1. Approaches to Learning Mathematics Scale (ALMS)

Approaches to Learning Mathematics Scale (ALMS) used in this study was developed by researchers in order to analyze the learning approaches of students in mathematics course. It was a 5 point Likert scale (Strongly Agree (5), Agree (4), Undecided (3), Disagree (2), Strongly Disagree (1)) composed of 33 items. The items of the scale were grouped under three headings: Deep, Surface and Strategic. The Cronbach Alpha reliability coefficient of the scale for the present study was 0.79. The reliability coefficients of the sub-scales were 0.83, 0.82 and 0.78 respectively. In deep learning approach, there were 11 items; in surface learning approach, there were 11; and in strategic learning approach, there were 11 items. “I prefer memorizing most of mathematics topic”, “I always think as if I would not acquire mathematics and feel anxious because of this" are examples of surface learning items; "It makes me feel bad when I do not understand a topic in a mathematics lesson", "I try to understand exactly what is intended to be questioned" are examples of deep learning items; "Generally, I prepare regularly for mathematics exams", "I spare time for studying mathematics during the day" are examples of strategic learning approach items. The evaluation in the scale was carried out not by looking at the total scores of the scale itself, but by looking at the scores taken from the sub-dimensions of it.

2.2.2. Spatial Ability Test (SAT)

In this study, the spatial ability was assessed by three components (spatial relations, spatial orientation and spatial visualization) which were accepted by Lohman (1988). Based on there was not any tool in Turkish literature that evaluated students' spatial abilities from these three aspects at the middle school level, Spatial Ability Test (SAT) was developed by researchers. In the initial draft of the test, there were twenty-eight questions and seven sections. Twelve questions of the test were about spatial visualization, eight questions were about spatial orientation, and eight questions were about spatial relations component. Two mathematics teachers and five mathematics teaching specialists in total of seven experts scrutinized those questions. The experts evaluated each question according to their suitability to the spatial ability component and theoretical framework. There were twenty-four questions and seven sections in the revised version of the test which was piloted on a group of 704 middle school students. With obtained data, test and items were analyzed. The item difficulty index and item discrimination index of each item were computed separately. The difficulty indexes of the items varied between 0.08 and 0.42. Average item difficulty level (p_{mean}) was 0.11 and the test was quite difficult (Tekindal, 2009). When discrimination indexes of the items included in the test were examined, it was seen that the lowest value was -0.01 and the highest value was 0.65. Other items' discrimination indexes varied between 0.38 and 0.64. Considering the discrimination index of one item was below 0.30, it was removed from the test. Average item discrimination level (r_{mean}) of the test was 0.24. Hence, the test was very good in terms of selectivity (Tekindal, 2009). The findings obtained showed that the test which was composed of twenty-three items was a valid and reliable measuring instrument. Cronbach's alpha reliability coefficient of the test for the study was found to be 0.82. The item analysis of the Spatial Ability Test was given in Table 2. An example of a question from the SAT was shown in the Appendix 1.

Table 2. *Item Analysis of the Spatial Ability Test*

Item	N	Mean	SD	Item difficulty index	Item discrimination index	Evaluation
M1_1	704	.52	.500	0.28	0.54	Medium difficulty and very good discrimination
M1_2	704	.57	.495	0.30	0.46	Difficult and very good discrimination
M1_3	704	.50	.500	0.28	0.53	Difficult and very good discrimination
M1_4	704	.55	.498	0.29	0.51	Difficult and very good discrimination
M2_1	704	.22	.413	0.14	0.49	Difficult and very good discrimination
M2_2	704	.32	.468	0.21	0.65	Difficult and very good discrimination
M3_1	704	.38	.486	0.21	0.50	Difficult and very good discrimination
M3_2	704	.34	.473	0.18	0.41	Difficult and very good discrimination
M3_3	704	.30	.458	0.18	0.49	Difficult and very good discrimination
M3_4	704	.37	.482	0.21	0.51	Difficult and very good discrimination
M4_1	704	.76	.425	0.38	0.48	Difficult and very good discrimination
M4_2	704	.58	.494	0.31	0.64	Difficult and very good discrimination
M4_3	704	.19	.393	0.08	-0.01	Difficult and not distinctive
M4_4	704	.46	.499	0.26	0.48	Difficult and very good discrimination
M5_1	704	.71	.455	0.38	0.42	Difficult and very good discrimination
M5_2	704	.54	.499	0.29	0.57	Difficult and very good discrimination
M5_3	704	.47	.500	0.26	0.62	Difficult and very good discrimination
M6_1	704	.49	.500	0.25	0.47	Difficult and very good discrimination
M6_2	704	.82	.388	0.42	0.38	Medium difficulty and good discrimination
M6_3	704	.81	.389	0.40	0.46	Orta güçlükte ve ayırt ediciliği çok iyi
M6_4	704	.71	.455	0.37	0.50	Difficult and very good discrimination
M7_1	704	.51	.500	0.29	0.52	Difficult and very good discrimination
M7_2	704	.43	.495	0.25	0.55	Difficult and very good discrimination
M7_3	704	.42	.494	0.24	0.46	Difficult and very good discrimination

2.2.3. 3D Geometrical Thinking Test (3DGTT)

The 3DGTT, containing twenty-four questions, was adapted by the researchers. The test was based on the test developed by Pittalis and Christou (2010). Researchers defined three skills for 3DGTT. Skills defined for 3DGTT were as indicated below:

1. Visualizing 3-dimensional objects
   i. Interconverting the different representations of 3-dimensional objects
   ii. Recognizing and creating the openings of 3D objects
2. Spatial construction
3. Conceptualizing the properties of 3D objects
   i. Recognizing the properties of 3D objects
   ii. Comparing the properties of 3D object
4. Measurement

3D Geometrical Thinking Test was prepared in a format of an achievement test that could be applied in mathematics lessons. Besides, different items were added by the researchers in compliance with the thinking types included in the sub-dimensions of the test. A draft of 26 questions was prepared for the pilot implementation of the test. Some questions contained multiple items. One example from the 3D geometrical thinking types of the test questions in the final form of the 3DGTT was given in Appendix 2. According to item analysis, the test was a medium difficulty test (average item difficulty is 0.60). Also, the test discriminative power was highly good (average item distinctiveness is 0.42) (Baykul, 2010; Tekindal, 2009).

The data obtained from the 3DGTT were scored as true-false (1-0). In this way, KR-20 (Kuder Richardson-20) method is used to calculate the reliability coefficient for dichotomous data (Baykul, 2010) and Cronbach's alpha coefficient is equal to KR-20 (Kuder Richardson-20) for this data (Kalaycı, 2014). Cronbach's alpha reliability method was used to determine whether the twenty-four problems in the test represent a homogeneous structure (Kayış, 2010). The Cronbach's alpha coefficient for the whole test was 0.83. Therefore, the scale was highly reliable (Kalaycı, 2014).

2.3. Data analysis

The data obtained from the SAT, 3DGTT and ALMS were analyzed quantitatively. It was checked whether the collected data showed normal distribution or not. Since there were more than 29 data for each group, Kolmogorov-Smirnov test results were analyzed for normality (Kalaycı, 2014). Normality analysis results showed that the data did not show normal distribution. An alpha level of 0.05 were accepted for assessing the analysis results. When making assessment about whether students' in the experimental and control groups SAT and 3DGTT test scores showed any difference according to their learning approaches, "Kruskal Wallis H Test Analysis" was conducted. When significant difference appeared, "Mann Whitney U Test" was implemented. In cases where the difference was significant in the Mann Whitney U Test results, the effect size (r) was calculated by dividing the z value by the square root of the total number of participants in the two groups (Fritz, Morris & Richler, 2012). The classification made by Cohen (1988) was taken into account in the interpretation of the effect size. Accordingly, 0.50 was considered as high impact, 0.30 as medium and 0.10 as small impact.

2.4. Procedure

The study was conducted during the second semester in the 2015-2016 academic year in the Mathematics Applications elective course. The course was adjusted two hours in a week for the aim of giving students opportunity of making proper mathematics applications for their levels and making them love mathematics and develop positive attitude towards it while improving their knowledge and abilities (MoNE, 2013). The duration of the study was eight weeks from March to May. While EDBM applications were implemented to the students in the experimental group, the traditional method was used in the control group. All of the lessons were conducted by the first researcher during the implementation process. Only just before starting the implementation of the application, the researcher was accompanied by the mathematics teacher for one week and students were informed about the activities. Concrete material supported activities and free mathematics applications and were carried out in students' regular classroom. On the other hand, computer-based mathematics applications were carried out in the school's computer laboratory. Both groups' spatial abilities, 3D geometrical thinking skills and approaches to learning mathematics were evaluated both before and after the study.

2.4.1. Implementing Engineering Design-Based Mathematics (EDBM) Activities

In the phase of developing engineering design-based mathematics (EDBM) activities of the research, different components of spatial ability were taken into consideration. The middle school mathematics curriculum of the Ministry of National Education's was reviewed. The learning objectives about spatial ability in middle school mathematics lesson teaching program MoNE (2013) were specified at all levels. 22 of these acquisitions were selected and they were classified according to spatial visualization, spatial orientation and spatial relations components. Engineering design-based mathematics activities are not prepared concerning students' learning approaches. Considering the nature of engineering design-based activities, it can be said that most of the activities are for the in-depth learning approach of students. Instruction in the EDBM group was module-based (that is, EDBM consisted of three modules and eight design tasks). Conditions of materials that would be used during implementation were took into consideration while creating the modules. The pilot study of the activities was conducted with eighth-grade students at two different middle schools in Istanbul in the 2014-2015 academic year. Students participating in the pilot study did not have previous experience with design-based mathematics applications. The teachers of the classes in which the pilot applications were carried out showed a positive attitude in a participatory manner. During the applications, they helped the researcher by being in the classroom. Feedback was received from the participating students and mentor teachers after the pilot implementation. This feedback has contributed to the development of educational activities which will be held prior to the actual application. Table 3 illustrates the distribution of EDBM activities according to content. Figure 1 includes a part of an engineering design-based mathematics activity example and a student response. An example of engineering design based mathematics applications is presented in Appendix 3.

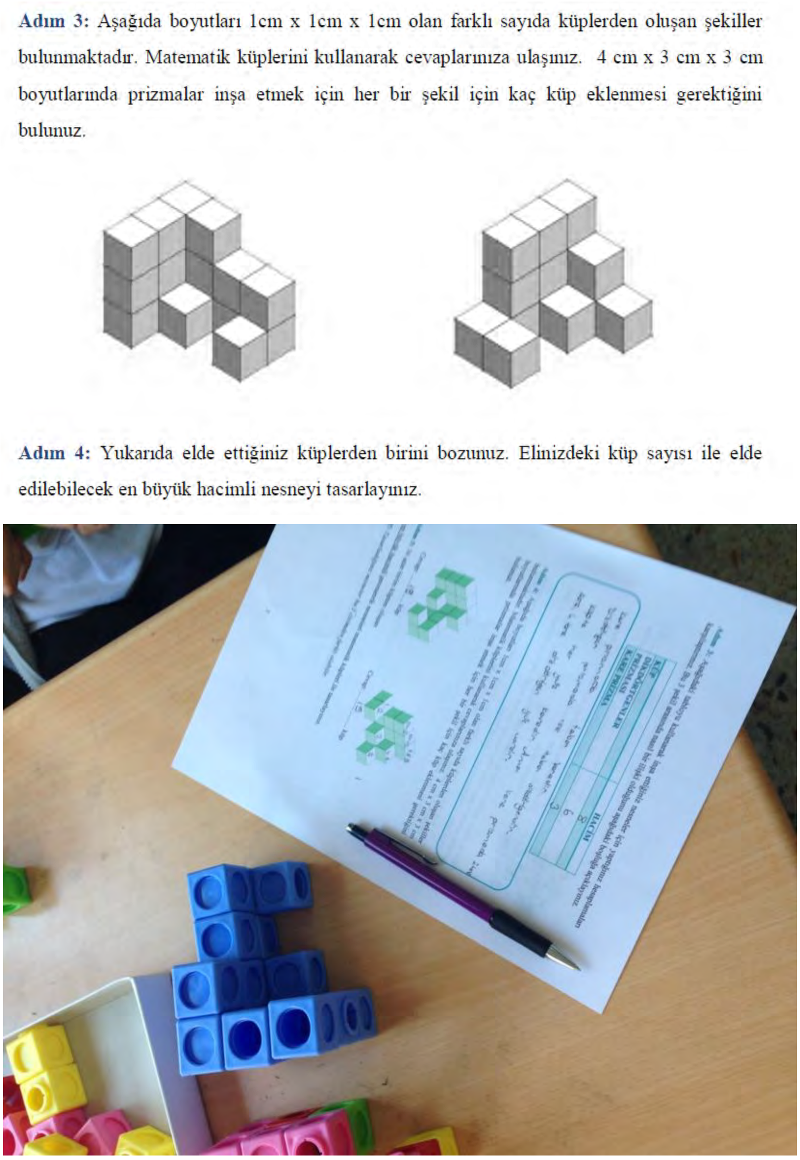

Figure 1. *Engineering design-based mathematics activity example and a student response*

Table 3. *Course content design according to learning objectives*

Weeks	Teaching content/tasks/tests	Learning objectives
Week 1	The description of the engineering design process and the content of activities	Students understand the engineering design circle and basic steps of the process
Week 2	Testing 3D geometrical thinking abilities of students before the implementation	The pre-implementation of 3DGTT
Week 3	Testing spatial abilities and approaches to learning mathematics of students before the implementation	The pre-implementation of SAT and ALMS
Week 4	Performing the first activity (I am designing geometric shapes with toy blocks)	Students recognize the prism of rectangles and determine their basic properties, form the volume of the rectangular prism and solve related problems, create different rectangular prisms with a given volume with unit cubes
Week 5	Performing the second activity (Wrapping a gift-box)	Students recognize the prism of rectangles and determine their basic properties, calculate the surface area of the rectangles prism, create the surface area relation of a vertical circular cylinder and solve related problems.
Week 6	Performing the third activity (The three-dimensional objects around us)	Students create the surface area formula of a vertical circular cylinder, pyramids, prisms and cone.
Week 7	Performing the fourth activity (I am exploring isometric drawings)	Students draw two-dimensional views of three-dimensional figures from different directions, create structures given drawings of views from different directions
Week 8	Performing the fifth activity (Geometrical nets)	Students recognize the vertical pyramids and prisms, determine the basic elements, construct and draw of them
Week 9	Performing the sixth activity (Let's rotate and move the shapes)	Students create the image of a planar shape that results from successive translations and reflections
Week 10	Performing the seventh activity (I am giving directions with my own coding system)	Students express the position of a point relative to another point on checkered or dotted paper by using direction and unit
Week 11	Performing the eighth activity (Engineers are wanted to work at a catering company)	Students form the volume formula of the rectangular prism and vertical circular cylinder, form the surface area formula of the rectangular prism and vertical circular cylinder and solve the related problems
Week 12	Testing 3D geometrical thinking abilities of students after the implementation	The post-implementation of 3DGTT
Week 13	Testing spatial abilities and approaches to learning mathematics of students after the implementation	The post-implementation of SAT and ALMS

2.4.2. Implementing Traditional Teaching

For the same learning objectives mentioned in Table 3 traditional teaching procedure was implemented to the students in the control group. Lessons were carried out by the first researcher in this group also by making use of direct instruction method and question-answer techniques. Teacher was in an active position during the teaching process. At the end of all topics, sample questions, which had been prepared by the researcher beforehand were solved with students' altogether.

3. Results

3.1. Spatial Ability

According to Kruskal Wallis H Test results, before the EDBM implementation, there was not a significant difference in terms of approaches to learning mathematics in SAT results of students in the experimental group [$X^2(2)=2.804$, $p>.05$]. Similarly, SAT pre-test results of students in the experimental group did not show any significant difference in terms of spatial ability's various components according to approaches to learning mathematics [$X^2_{spatial\ relations}(2)=2.19$, $p>.05$; $X^2_{spatial\ visualization}(2)=5.777$, $p>.05$; $X^2_{spatial\ orientation}(2)=1.691$, $p>.05$]. Kruskal Wallis H Test was implemented to students in the experimental group to find out whether their SAT post-test results showed any significant difference according to approaches to learning mathematics or not.

Table 4. *Kruskal Wallis H post-test results of the experimental group according to approaches to learning mathematics*

Group	**Approaches to learning mathematics**	**N**	**Mean Rank**	**sd**	X^2	**p**
Experimental	Deep	5	26.10	2	8.252	.016*
	Strategic	26	18.21			
	Surface	4	6.50			

*p<.05

The results given in Table 4 showed that there was a significant difference in SAT post-test results of the students in the experimental group according to approaches to learning mathematics [$X^2(2)=8.252$, $p<.05$]. For the Kruskal Wallis test, the effect size was calculated separately for both groups. The values obtained for both groups were given below in the Mann Whitney U test results. SAT post-test results of the students in the experimental group were compared with Mann Whitney U test to find out in which groups this difference appeared.

Table 5. *Mann Whitney U test results of SAT post-test according to approaches to learning mathematics*

Group	**Approaches to learning mathematics**	**N**	**Mean Rank**	**Sum of Ranks**	**U**	**p**
Experimental	Deep	5	22.30	111.50	33.50	.089
	Strategic	26	14.79	384.50		
	Deep	5	6.80	34.00	1.00	.027*
	Surface	4	2.75	11.00		
	Strategic	26	16.92	440.00	15.00	.023*
	Surface	4	6.25	25.00		

*p<.05

According to the Mann Whitney U Test results, there was not any significant statistical difference in the SAT post-test results of students in the experimental group who preferred deep and strategic learning approaches [U=33.50, p>.05]. On the other hand, there was a significant difference in the SAT post-test results of students who preferred deep and surface learning approaches [U=1.00, p<.05]. This difference in effect size (r = .32) were found to be medium. SAT post-test scores mean rank of the students who preferred deep learning approach was higher than the scores of students who preferred surface learning approach. This result clearly showed that spatial abilities of students who adopted deep learning approach was higher than spatial ability levels of students who adopted surface learning approach. Similarly, there was a significant difference in SAT post-test results of students who preferred strategic and surface learning approaches [U=15.00, p<.05]. This difference in effect size (r = .38) were found to be medium. SAT post-test scores mean ranks of students who preferred strategic learning approaches were higher than the scores of students who preferred surface learning approach. This result showed that students who adopted strategic learning approach had higher spatial abilities than the students who adopted surface learning approach.

Since spatial ability was analyzed in three different types, post-test scores of each component of SAT were also analyzed separately. To determine whether SAT post-test results in the experimental group showed any significant difference according to approaches to learning mathematics, each component was evaluated by Kruskal Wallis H Test separately.

Table 6. *Kruskal Wallis H test results of SAT post-test components according to approaches to learning mathematics*

Spatial Ability Component	**Approaches to learning mathematics**	**N**	**Mean Rank**	**sd**	X^2	**p**
Spatial Relations	Deep	5	28.40	2	8.578	.014*
	Strategic	26	17.33			
	Surface	4	9.38			
Spatial Visualization	Deep	5	26.30	2	9.504	.009*
	Strategic	26	18.33			
	Surface	4	5.50			
Spatial Orientation	Deep	5	22.00	2	4.903	.018*
	Strategic	26	18.77			
	Surface	4	8.00			

*p<.05

According to Table 6, there was a significant difference in the scores of experimental group students' SAT different components' post-test results according to approaches to learning mathematics [$X^2_{spatial\ relations}(2)=8.578$, $p<.05$; $X^2_{spatial\ visualization}(2)=9.504$, $p<.05$; $X^2_{spatial\ orientation}(2)=4.903$, $p<.05$]. For the Kruskal Wallis test, the effect size was calculated separately for both groups. The values obtained for both groups were given below in the Mann Whitney U test results. With intend to find out in which groups these differences appeared, SAT sub-components' post-test scores were compared with Mann Whitney U Test according to students' approaches to learning mathematics.

Table 7. *Mann Whitney U test results according to SAT components post-test scores according to approaches to learning mathematics*

Spatial Ability Component	Approaches to learning mathematics	N	Mean Rank	Sum of Ranks	U	p
Spatial Relations	Deep	5	24.60	123.00	22.00	.017*
	Strategic	26	14.35	373.00		
	Deep	5	6.80	34.00	1.00	.024*
	Surface	4	2.75	11.00		
	Strategic	26	16.48	428.50	26.50	.109
	Surface	4	9.13	36.50		
Spatial Visualization	Deep	5	22.30	111.50	33.50	.085
	Strategic	26	14.79	384.50		
	Deep	5	7.00	35.00	.00	.013*
	Surface	4	2.50	10.00		
	Strategic	26	17.04	443.00	12.00	.013*
	Surface	4	5.50	22.00		
Spatial Orientation	Deep	5	18.30	91.50	53.50	.525
	Strategic	26	15.56	404.50		
	Deep	5	6.70	33.50	1.50	.033*
	Surface	4	2.88	11.50		
	Strategic	26	16.71	434.50	20.50	.050*
	Surface	4	7.63	30.50		

*p<.05

There was a significant difference in students' spatial relations component post-test scores who preferred deep and strategic learning approaches [U=22.00, p<.05]. This difference in effect size (r = .48) were found to be high. The mean rank of SAT post-test scores of students who preferred deep learning approach was higher than the scores of students' who preferred strategic learning approaches. This result clearly showed that spatial relations abilities of students who adopted deep learning approach were much higher than abilities of the students who adopted strategic learning ability. Similarly, there was a significant difference in SAT post-test scores of the students who preferred deep and surface learning approaches [U=1.00, p<.05]. This difference in effect size (r = .34) were found to be medium. SAT spatial relations component post-test mean ranks of students who preferred deep learning approach was higher than SAT spatial relations component post-test mean rank of students who preferred surface learning approach. This result obviously showed that spatial relations abilities of students who adopted deep learning approach were much higher than the students who adopted surface learning approach. There was not any significant difference in the spatial relations component post-test results of students who preferred strategic and surface learning approaches [U=26.50, p>.05].

There was not any significant difference in students' spatial visualization component post-test scores who preferred deep and strategic learning approaches [U=33.50, p>.05]. It can be seen clearly that there was a significant difference in the scores of students who adopted deep and surface learning approaches [U=0.00, p<.05]. This difference in effect size (r = .28) were found to be medium. This result clearly showed that spatial visualization abilities of students who adopted deep learning were much higher than students who adopted surface learning approach. Similarly, there was a significant difference in spatial visualization component post-test results of students who preferred surface and strategic learning approaches [U=12.00, p<.05]. This difference in effect size (r = .29) were found to be medium. SAT spatial visualization component post-test scores mean ranks of students who preferred strategic learning approach were much higher than students who preferred surface learning approach. This result showed that spatial visualization abilities of students who adopted strategic learning approach were much higher than the students who adopted surface learning approach.

There was not any statistically significant difference in the SAT spatial orientation component post-test scores of students who adopted deep and strategic learning approaches [U=53.50, p>.05]. There was a significant difference in SAT spatial orientation component post-test scores of students who preferred deep and surface learning approaches [U=1.50, p<.05]. This difference in effect size (r = .30) were found to be medium. SAT spatial orientation component post-test scores mean ranks of students who preferred deep learning approach were much higher than students who preferred surface learning approach. This result clearly showed that spatial orientation abilities of students who adopted deep learning approach were much higher than the students who adopted surface learning approach. Similarly, there was a significant difference in SAT spatial orientation component post-test scores of students who adopted strategic and surface learning approaches [U=20.50, p<.05]. This difference in effect size (r = .29) were found to be medium. SAT spatial orientation component post-test scores mean ranks of students who preferred strategic learning approach were much higher than students who preferred surface learning approach.

Similarly, there was not any significant difference in the SAT pre-test scores of students in the control group according to approaches to learning mathematics [$X^2(2)$ =1.286, p>.05]. After the implementation, it was analyzed whether SAT post-test results of students in the control group showed any difference according to approaches to learning mathematics. Kruskal Wallis H Test was implemented to find out whether SAT post-test scores of the students in the control group showed any significant difference or not.

Table 8. *Kruskal Wallis H post-test results of the control group according to approaches to learning mathematics*

Group	**Approaches to learning mathematics**	**N**	**Mean Rank**	**sd**	X^2	**p**
	Deep	10	19.75			
Control	Strategic	27	20.54	2	0.146	.930
	Surface	3	22.67			

*p<.05

According to the results presented in Table 8, there was not a significant statistical difference in SAT post-test scores of the students in the control group according to approaches to learning mathematics [$X^2(2)$=0.146, p>.05].

3.2. 3D Geometrical Thinking Skills

According to Kruskal Wallis H Test results, there was not any significant difference in 3DGTT pre-test results of students in the experimental group according to approaches to learning mathematics [$X^2(2)$ =.440, p>.05]. Kruskal Wallis H Test was implemented after the EDBM applications to find out whether 3DGTT post-test scores of the students in the experimental group showed any significant difference according to students' approaches to learning mathematics.

Table 9. *Kruskal Wallis H post-test results of the experimental group according to approaches to learning mathematics*

Group	Approaches to learning mathematics	N	Mean Rank	sd	X^2	p
Experimental	Deep	5	26.00	2	3.073	.215
	Strategic	26	16.54			
	Surface	4	19.20			

*p<.05

According to the results presented in Table 9, there was not any significant difference in 3DGTT post-test scores of the students in the experimental group according to students' approaches to learning mathematics [$X^2(2)=3.073$, $p>.05$].

There was not any significant difference in 3DGTT pre-test scores of the students in the control group according to students' approaches to learning mathematics [$X^2(2)=1.910$, $p>.05$]. At the end of the implementation, Kruskal Wallis H Test was implemented to find out whether 3DGTT post-test scores of the students in the control group showed any significant difference or not.

Table 10. *Kruskal Wallis H post-test results of the control group according to approaches to learning mathematics*

Group	Approaches to learning mathematics	N	Mean Rank	sd	X^2	p
Control	Deep	10	15.00	2	3.018	.221
	Strategic	27	22.22			
	Surface	3	18.85			

*p<.05

According to the results presented in Table 10, there was not any significant difference in 3DGTT post-test scores of the students in the control group according to approaches to learning mathematics [$X^2(2)=3.018$, $p>.05$].

4. Discussion and Conclusion

There was a significant difference in spatial abilities of the students in the experimental group according to approaches to learning mathematics. The spatial abilities of students who adopted deep learning approach were higher than students who adopted surface learning approach. Similarly, the spatial abilities of students who adopted strategic learning approach were higher than the abilities of the students who adopted surface learning approach. There was not any significant difference in spatial abilities of students who preferred deep and strategic learning approaches. In general, the same results were obtained for spatial ability's spatial visualization and spatial orientation skills. Apart from the other two components, spatial relations abilities of students who adopted deep learning approach were higher than students who adopted surface learning approach. Similarly, spatial relations abilities of students who adopted deep learning approach were higher than the abilities of the students who adopted strategic learning approach. There was not any significant difference between students who preferred strategic and surface learning approaches. In addition, there was not a significant statistical difference in spatial abilities (and sub-components of spatial ability) of the students in the control group according to approaches to learning mathematics.

It can be concluded from all the results given above about the Spatial Ability, not all the students who have different learning approaches benefit equally from engineering design-based mathematics applications in terms of spatial abilities during the education process. The results obtained in this research show consistency with the results of other studies claiming that integrating design-based applications to the teaching process provide students opportunities for adopting a deep approach (Purzer & Shelley, 2018). Engineering design have the potential of serving as a tool to make students deeply busy with science and math contents, lots of factors may affect (e.g. content, justification need and teacher factor) students' learning science and math contents more deeply (Mathis et al., 2018). In general, spatial abilities (and sub-components of spatial ability) of students who learned with deep learning approach in the experimental group are much higher than the students who learned with surface learning approach. This result can only be explained by the fact that meaningful learning is matching with deep learning and similarly, rate learning is matching with surface learning (Offir, Lev & Bezalel, 2008). Besides, the reason of why students who are learning with surface learning approach have low spatial ability levels is may be fear of failure and lack of self-confidence. Students who learn with strategic learning approach make use of both deep and surface learning approaches to get the highest score and they prefer the best approach which make them more successful (Makinen, 2003). Although eight-week-long EDBM activities brought a different perspective to the students about mathematics lesson; factors like education system in our country, exam anxiety and press over them about being successful may drove them to get the highest scores to be successful. Therefore, they mainly may tend to choose strategic learning approach again. It can be also concluded that the reason of why there is not any significant difference in spatial abilities, spatial visualization and spatial orientation skills of the students in the experimental group who learned with deep and strategic learning approaches is that the education which was carried out by engineering design-based mathematics applications motivated students who were learning with strategic learning approach to learn with deep learning approach. Because, students who use strategic learning approach can use both deep and surface learning approaches depending on the teaching environment (Entwistle & Tait, 1990). Teachers who implement traditional teaching methods are still in majority. Various studies show that, an education, which is carried out with traditional methods, may result in memorizing the real information and does not provide meaningful learning (Loverude, Kautz & Heron, 2002). Therefore, traditional teaching orients students mostly to surface learning approach as part of its nature. It can be said that traditional approach has not a quality for students to concretize the differences between learning approaches. Past and ongoing learning experiences of students may have effect on getting this result. It may be required to investigate the effects of similar teaching approaches on students' spatial abilities in a long time period.

There is not any significant difference in 3D geometrical thinking skills of students in the experimental group according to approaches to learning mathematics. This finding of the study shows that students, who have different learning approaches, do not show any difference on having same level of utilizing EDBM applications teaching process on the basis of three-dimensional thinking abilities. In addition, it is concluded that there is not any significant diference in 3D geometrical thinking skills of students in the control group according to approaches to learning mathematics. Similar results obtained for the students in the control group about their spatial abilities. Traditional teaching causes to memorizes the true knowledge most of the time and do not provide meaningful learning for similar justifications (Loverude, Kautz & Heron, 2002) and it can be said that traditional approach has not a structure to clarify the difference between learning approaches of students. Post and ongoing learning experiences of students may have effect on getting this result. Maybe, long-term studies are need to be carried out to investigate the effects of traditional teaching on students' 3DGTT abilities. Because of the fact that 3DGTT connected to stereometric topics which is involved in school's curriculum (Pittalis & Christou, 2010), students may be continuing their former studying habits. Hence, students, that have different learning approaches, might have been affected in similar proportions by the education process and it might not have been obtained significant differentiation in terms of three-dimensional geometric thinking abilities. All the information given above can be applied as the explanation of students' in the experimental group who took part in mathematics applications not showing any significant improvement in terms of three-dimensional geometric thinking ability according to mathematics learning approaches.

5. Suggestions for Future Research

Mathematics differs from other sciences in many ways in that it is an abstract discipline by its nature. Therefore, evaluating mathematics learning approaches differently from learning approaches in other fields can provide more reliable results. Mathematics teachers need to carry out teaching activities by considering students' learning approaches. More convenient teaching environments can be provided to students in mathematics lessons to make them prefer deep learning approach. Accordingly, technology-supported activities can be included in a student-centred teaching environment. Therefore, students should be oriented to think relational in the teaching environment. At this stage, mathematics teachers can configure lessons by orientating students to think during the lesson and design the lessons in such a way that makes it possible to connect former learnings. With the help of these kinds of activities, students can be both oriented to adopt deep learning approach and their spatial and three-dimensional thinking abilities can be supported. The process of creating an activity based on engineering design is a time consuming and challenging process. The activities should be appropriate to address the subject and gain the learning objectives to the students. The main recommendation for this subject is to increase the number of such activities in a way that can be directly related to mathematical issues and gain.

Besides, the following suggestions can be made to mathematics teachers and researchers in the field in light of the findings of the research:

In this research, engineering design-based mathematics applications were carried out without being bound to a specific subject and taking into account the spatial abilities in the curriculum. It may be suggested to develop unit and subject-based applications for further studies. The effect of such practices on students' approaches to learning mathematics can be examined.

According to the relevant literature, the factors that may affect students' learning approaches should not be considered on a single factor, and teaching environments should be designed considering that there may be more situations and factors that will affect students' learning approaches. Therefore, more comprehensive research can be done by including other factors that affect the learning approaches of students in mathematics courses.

The following situations can be mentioned as the limitations of the study:

Regarding the sampling, there were only 75 participants in the complete study. Therefore, the results may not be generalized to students in different grades and contexts. For further experimental research under a similar context, it is needed with larger sample sizes to demonstrate that the results were not achieved by chance. Besides, other complementary 3D geometrical reasoning types are not examined for this study. The effect of EDBM activities on other reasoning types can also be investigated separately for future studies. Teaching three-dimensional geometry should include tasks that involve a wide variety of 3D geometrical situations, apart from specific school geometry tasks.

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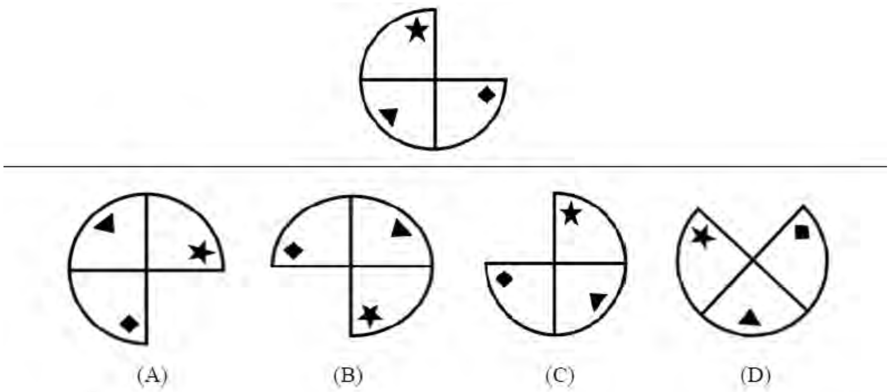
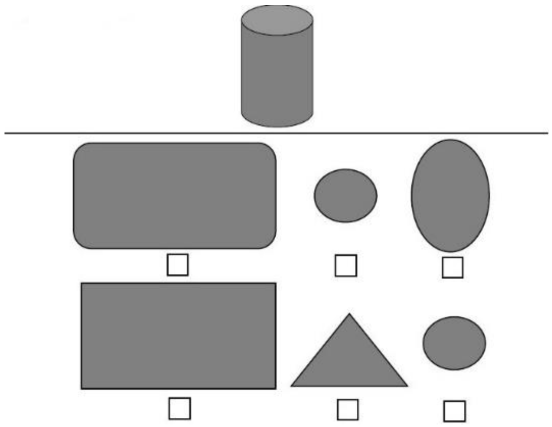
Appendix 1. An example question for the Spatial Ability Test (SAT)



In the question, there is one figure above the line and four figures below the line. Three of the figures which are below the line are the rotated form of this figure and one is not. Students are asked to find which figure is not the rotated form of this object.

Appendix 2. An example question for the 3D Geometrical Thinking Test (3DGTT)



Mark which of the figures below will be combined to create the CYLINDER shape above the line.

Appendix 3. An example of engineering design-based mathematics activity

I AM GIVING DIRECTIONS WITH MY OWN CODING SYSTEM

General description: In this activity, students create various expressions with a simple coding language, look for alternative ways to solve the problem, experience the engineering design process, develop their mathematical reasoning skills, develop their spatial abilities, learn the location information of different places according to each other and express them with the coding language, It is aimed to reinforce the addition and subtraction issues.

Related fields: Mathematics, Engineering

Spatial ability component: Spatial Orientation

Mathematical Achievements: Express the position of a point on a piece of squared or dotted paper relative to another point using direction and unit.

Participants: It can be carried out with the required number of middle school students at the 6th grade and above.

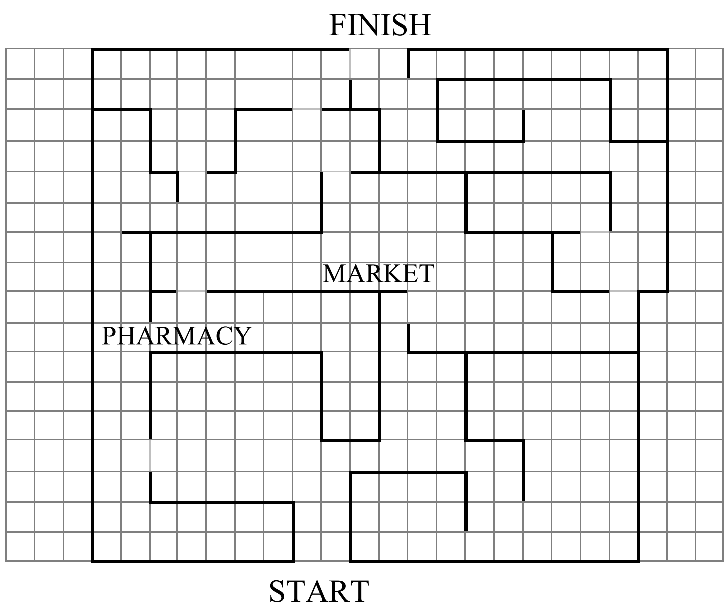
Required materials: Worksheet, pencil, eraser and other optional materials

Duration: 2 lesson hours (80 minutes)

Implementation of the activity

Students are free to use materials since the activity is included in the free mathematics applications module of the research.

In accordance with the stage of defining the problem, which is the first step of engineering design based learning, students are given a scenario at the beginning of the design activity. This scenario is about helping a visually impaired person go from one place to another. Students are asked to take a visually impaired person to the home from the point they are following by following the map provided. The map is in the form of a maze and there are multiple ways to reach the destination. There are also places such as pharmacy, hospital, market, school on these roads. Students are asked to create a route and express it in coding language. However, the path they should follow must have some features. These features are also the criteria and restrictions set for the activity.



1. Do not go diagonally.
2. It is represented by upward (+), downward (-), right direction (+), left direction (-).
3. Find the shortest path to your destination.
4. Visit the pharmacy or market on the road.

At the stage of determining possible solutions in the engineering design process, students are asked what route they suggest to reach the goal. Students will try to find the shortest path using the above criteria and restrictions and bring the visually impaired person home. With the activity, students are also associated with the subject of addition and subtraction in integers.

In determining the shortest route, students must consider the above and right directions (+) and down and left directions (-). In the continuation of this phase, students are asked to fill in the table given in the worksheet on the shortest path, considering all the routes that can be created.

During the analysis of the solutions, students are asked to examine and compare the values they fill in the table. From the stage of optimizing the solutions, the students are expected to choose the most optimal among them by evaluating all the possibilities created systematically. Also, at this stage, it is discussed together whether the paths chosen by the students are the shortest path, whether there is another alternative path that can be created, and their reasons are explained. The last determined path is shown on the labyrinth and its expression is written in the language of coding. During the communication phase, students explain the path they chose to the class together with their reasons.