Effects of Teaching Activities via Google Sketchup and Concrete Models on Spatial Skills of Preservice Mathematics Teachers[1]

Candaş Uygan[2] and Aytaç Kurtuluş[3]

Article History
Received: 26 February 2016
Accepted: 18 September 2016

Abstract: The aim of this study was to investigate the impact of teaching activities supported by Google SketchUp, which is a 3–Dimensional modeling software, and concrete models on the basic skills related to spatial ability in teaching geometric solids. The study sample consisted of 72 preservice teachers who were studying elementary mathematics education in 2009-2010 academic–year in a state-funded university in Central Anatolia, Turkey. This was an experimental study. The study used a pretest posttest control group design and included two experimental groups and a control group. One of the experimental groups was taught using Google SketchUp while the other one was taught with concrete model-aided teaching activities. The activities, designed for the control group, were carried out with some traditional teaching tools such as paper, pencil and classroom writing board. The Santa Barbara Solids Test (SBST) and the Purdue Spatial Visualization Test (PSVT) were used to measure spatial ability. The SBST measures the ability to mentally visualize the cross-sections of 3D objects. The PSVT consists of three parts: "Developments", which measures skills to visualize a 3D object based on its surface development; "Rotations", which measures skills to mentally rotate 3D objects; and "Views", which measures skills to visualize different views of 3D objects. The study identified significant increases in the scores received for all of the tests by the group using Google SketchUp, in the scores received for the SBST and Developments part by the group using concrete models, and in the scores received for only the Developments part by the control group. Also, the posttest average score received for the "Views" part by the experimental group using Google SketchUp was significantly higher than the score of the experimental group using concrete models and the control group.

Keywords: Spatial ability, Google SketchUp, concrete model, geometric solids, preservice elementary mathematics teacher

DOI: 10.16949/turkbilmat.273993

1. Introduction

It is known that various disciplines such as physics, mathematics, engineering, surgery and arts put great emphasis on spatial ability that involves visualization of images and movements of objects in the mind. Hence many researchers have focused on definition, components, measurement, correlations with various skills and development of spatial ability for a long time (Carroll, 1993; Linn & Petersen, 1985; Lohman, 1988; Maier, 1998; McGee, 1979; Olkun & Altun; 2003; Sorby, 1999; Yılmaz, 2009). On the other side the findings of many studies indicated that high level spatial skills support to geometrical thinking and achievement (Battista, 1990; Fennema & Sherman, 1977; Guay & McDaniel, 1977; Naraine, 1989; Tso & Liang, 2002). Researchers emphasized that improvement of spatial ability is crucial for geometry education from preschool to high school grade by NCTM (2000) and national mathematics education programs (Ministry of National Education [MoNE], 2009a; MoNE, 2009b). At the same time, another important issue is

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[1] This study is a part of Candaş Uygan's master thesis (Uygan, 2011).

[2] Research Assistant, Eskişehir Osmangazi University, Mathematics Education Department, Türkiye, *uygancandas@hotmail.com*
[3] Assoc. Prof. Dr., Eskişehir Osmangazi University, Mathematics Education Department, Türkiye, *aytackurtulus@gmail.com*

development of spatial skills of preservice teachers who are supposed to teach students involving the use of this ability and also instructional tools that could be used effectively for this purpose. The results of many researches have indicated that dynamic software and concrete model based activities could provide many opportunities to improve spatial skills (Baki, Kösa & Güven, 2011; Cohen & Hegarty, 2008; Güven & Kösa, 2008; Sundberg, 1994; Weidemann, 1990). Therefore activity–task designs that include virtual dynamic models made by handwork or software became to be used commonly for improvement of spatial ability. However, some recent studies have suggested that Google SketchUp (GSU), a 3D modeling software, could be used as an alternative tool for learning of geometric solids and training of spatial skills (Fleron, 2009; La Ferla et al., 2009). In this regard some applications that the software provide involve analyzing 3D objects from different viewpoints, rotating objects around different axis, cutting 3D objects and exhibiting cross sections.

In this study, we aimed to investigate the impact of GSU based training activities within geometric solids on the spatial skills of preservice elementary mathematics teachers and to analyse its effectiveness comparing to applications in which concrete models and traditional instructional tools were used. In this context, we focused on three basic components of spatial ability, which are spatial visualization (mentally visualizing the new forms of a 2D or 3D object after its parts are changed), spatial relations (mentally visualizing the rotations of objects in mind), and spatial orientation (mentally visualizing views of an object from different viewpoints). Depending upon these components and Unit of Geometric Solids embedded in geometry course at preservice teacher training program, we designed training activities with aim to improve four spatial skills that are capabilities “to visualize cross–sections of an geometric solids”, “to visualize an geometric solids based on its surface development”, “to mentally rotate an geometric solids” and “to visualize different views of an geometric solids”. Research problems were designed as below:

1. What is the effect of GSU based training activities within geometric solids on the spatial skills of preservice elementary mathematics teachers?

2. Is there statistically significance difference among spatial ability improvements of three groups, which attended to different trainings based on using GSU, concrete models and traditional instructional tools separately?

1.1. Conceptual Framework

The framework of the study consist of research relevant components of spatial ability, importance of spatial skills in mathematics education, training of spatial ability at different school levels and also in the education of preservice mathematics teachers, instructional tools that include concrete models, dynamic geometry software and GSU used to develop spatial skills.

1.1.1. Components of Spatial Ability

Although there is no a universal definition of spatial ability, many studies aiming to explore this ability defined and examined various spatial components such as visualization, mental rotation, spatial orientation and spatial relations (Carroll, 1993; Linn & Petersen, 1985; Lohman, 1988; Maier, 1998; Sorby, 1999). McGee (1979) stated that spatial ability consists of two components and termed these sub-components as "spatial visualization" and "spatial orientation". Spatial visualization is about the skills to mentally control, rotate, and manipulate objects in space while spatial orientation involves the ability to visualize the appearance of an object from different viewpoints. The main difference between spatial orientation and spatial visualization is the subject's imagining his or her body movements around fixed objects (Turğut, 2010; Yılmaz, 2009). Lohman (1988) suggested a new component named as "speeded rotation" within spatial ability in addition to the components suggested by McGee and noted that this skill involves mental rotation of 2D shapes. In this sense, speeded rotation skill is about rapid mental activities, but spatial visualization is about multiple and complex mental skills like performing surface development of an object.

Suggesting another classification, Linn and Petersen (1985) analyzed spatial ability under three components and defined these components as "spatial visualization", "mental rotation" and "spatial perception". In this classification, spatial visualization was described in a way similar to the definitions by McGee and Lohman, where mental rotation was explained as the ability to mentally rotate 2D and 3D shapes and spatial perception was described as the ability to identify the relations between a real object and its representation on paper.

Carroll (1993), on the other hand, suggested five main components for spatial ability: "visualization", "spatial relations", "closure speed", "flexibility of closure" and "perceptual speed". In this categorization, while visualization was used in the same way with the concept of "spatial visualization" in the literature, spatial relations referred to the ability to visualize rotation of 3D shapes in space. In this regard, spatial relations included the properties of "mental rotation" ability defined by Linn and Petersen (1985) and Lohman (1988). Perceptual speed was explained as the speed in which an arrangement is formed out of a disorganized group of shapes. This component involves skills such as comparing pairs of stimuli and identifying a configuration. Closure speed includes the ability to integrate incomplete or unrelated parts into a meaningful whole. While performing these operations, no information is provided about what to look for and analyze in the items given. Flexibility of closure involves the ability to identify the hidden items in a big and complex structure. While performing these operations, on the other hand, information is provided about what to search for in the items given.

Maier (1998) distinguished between five components of spatial ability: "visualization", "mental rotation", "spatial perception", "spatial orientation" and "spatial relations". In this categorization, visualization involves the ability to visualize situations when items make certain moves such as moves of the parts of a shape and development of a 3D object.

Mental rotation involves ability of rapid mental rotation of 2D and 3D shapes. Spatial relations include the ability to understand the relations between shapes and their parts and with each other. For example, being able to recognize an object based on its appearance from a different viewpoint is considered in this category. In this regard, the concept of spatial relations was defined differently from other researchers and it was recognized as a skill separate from "mental rotation". Spatial orientation involves the subject's imagining that he or she mentally oriented towards another point in space. Finally, spatial perception involves understanding and positioning vertical and horizontal of the figures shapes for a misleading stimulus.

Sorby (1999) proposed two components of spatial ability: "spatial visualization" and "spatial orientation". In this categorization, spatial orientation is the ability of the subject to mentally change his or her viewpoint towards an object, whereas spatial visualization is the ability to mentally move an object. In Sorby's classification, mental rotation or spatial relations were not considered as separate components, but they were considered within spatial visualization. On the other hand, Olkun and Altun (2003) considered spatial ability into two components: spatial visualization and spatial relations. Olkun and Altun (2003, p. 87) explained spatial visualization as "the ability to mentally visualize the new forms 2D and 3D objects consisting of single or multiple components when they are moved in space". Also, they defined spatial relations as "the ability to mentally rotate 2D and 3D objects as a whole or to recognize shapes based on their rotated forms" (Olkun & Altun, 2003, p. 87).

According to all these classifications in the literature, spatial visualization is generally defined as the ability to mentally visualize the new forms of a 2D or 3D object after its parts are moved. The main difference that distinguishes this component from the others is that it involves complex and multiple steps with mental operations. An example of these mental operations is the ability to make a closure of the surface developments of 3D shapes. Secondly, spatial relations ability involves the capability to visualize the rotations of 2D or 3D shapes mentally. Thirdly, spatial orientation is generally referred as the ability to mentally visualize how 3D objects look from different viewpoints. Spatial visualization involves multiple steps and complicated mental operations, whereas spatial relations and spatial orientation involve rapid mental operations. These components defined above were taken as three basic skills related to spatial ability.

Today, many disciplines and professions require the use of different skills related to spatial ability. One of these areas is mathematics teaching and, as a part of mathematics teaching, geometry teaching attaches great importance to the development of these skills (MoNE, 2009a; MoNE, 2009b; NCTM, 1989; NCTM, 2000).

1.1.2. Spatial Ability in Mathematics Education

Spatial thinking and mathematical thinking are not the same skills, but they are related in that spatial thinking supports mathematical thinking (Turğut, 2010). In fact, this relation was reported by many studies conducted with students in different levels of education

(Fennema & Sherman, 1977; Guay & McDaniel, 1977; Sherman, 1979 as cited in Shieh, 1985). Spatial ability is also important in learning geometry and developing the level of geometric thinking. Mitchelmore (1976, as cited in Capraro, 2001) reported that students with a high score from the spatial visualization test also demonstrated a high level of achievement in geometry and the ability to visualize 3D objects, which is directly correlated with solving geometric problems. In a study carried out with 120 6^{th} Grade students, Karaman and Toğrol (2000) made a multiple regression analysis and found that spatial orientation was the most effective component in mathematics scores followed by spatial visualization. In another study with high-school students about the relationship between spatial visualization, logical reasoning, geometry achievement and gender, it was found that spatial visualization and logical reasoning were positively correlated with geometry achievement (Battista, 1990). In addition to this, a study with university students (Naraine, 1989) and another with 8^{th} Grade students (Tso & Liang, 2002) showed that there was a significant relationship between these students' geometric thinking levels and their spatial ability. In sum, results indicate that spatial ability could be a strong cognitive factor in developing geometric thinking of students in different education levels.

Spatial ability is considered as an essential ability in learning geometry, in which visual images are important. Reports of the NCTM (1989) showed that there is a need to develop students' spatial intelligence in geometry teaching. Also the NCTM reports in 2000 stated that this ability is an important means in learning geometry and emphasized the need to improve students' visualization skills through concrete materials and technology. Similarly, spatial ability is highlighted in the mathematics curriculums of the Ministry of National Education of Turkey (MoNE). In the MoNE's mathematics curriculum for Grades 1-5, the first general objective of geometry subject area is stated as "students are able to develop and use skills related to spatial (topological, directional, proximal) relations" (MoNE, 2009a). Also, in the MoNE's mathematics curriculum for Grades 6-8, one of the objectives of geometry subject area, which is stated as "students develop their spatial ability using multiple cubes", is directly aimed to develop spatial ability. In addition, the objectives stated as "students are able to draw views of a structure formed with identical cubes from different points of view" and "students are able to make a perspective drawing of a cube or a prism at a certain distance" in 6th Grade Geometric Objects and Projection subject are related to spatial orientation skills. Finally, while Transformation Geometry in 7th Grade is aimed to develop spatial relations skill, the activities in Geometric Objects in 8th Grade about surface developments of objects and the objective which is stated as "students are able to predict intersecting surface of an object" are related to spatial visualization. The geometry subjects covering these objectives are aimed to develop spatial ability (MoNE, 2009b).

NCTM (2000) and the MoNE (2013) stated that the use of visual aids and computer technology is critical for teaching geometry subject area. Proper use of these means both promotes learning this subject area and improves spatial skills, which are included among the primary objectives of its curriculum.

1.1.3. Tools Used in Spatial Ability Development

According to Gutierrez (1992), students learn geometric shapes based on three different representations: concrete models, computer-generated representations and planar illustrations drawn on paper or board. Planar illustrations are most commonly used and provide holistic information about a shape, but they are static and do not provide sufficient contribution to mental manipulations. On the other hand, there is substantial research on the strengths of concrete models and computer representations in developing geometric thinking and spatial ability.

The “concrete” concept in the term “concrete model” is used to explain materials’ functions and to emphasize the role of learning from the concrete to the abstract (Goldsby, 2009). Kennedy (1986) defined concrete materials as objects that can be felt through several senses, be touched and manipulated manually. Moyer (2001) defined these tools as materials designed to represent abstract mathematical concepts in a concrete and clear way. According to Baykul (2004), learning geometric shapes and concepts should be supported with activities in which geometric properties are examined, generalizations are made and then these generalizations are controlled by means of concrete models. In this sense, various objects, shapes and concrete tools should be used so that geometry becomes uncomplicated and easy to learn. Therefore, models of geometric shapes should be prepared by students with paper, paperboard and plastic or these models should be prepared and integrated into teaching by teachers.

The position of concrete models in geometry education has been examined by various researchers. For example, Sundberg (1994) compared the effects of training with concrete models and traditional geometry teaching on the spatial ability and mathematics achievement of 650 students in 6th, 7th and 8th Grades and found that concrete models were effective teaching tools in developing spatial ability. In another similar study, Weidemann (1990) investigated the effect of concrete models on teaching problems about “locus point” in geometry lessons in secondary education. In Weidemann’s study, there were three groups: the first group was taught by using concrete models, but the students examined the models in the teacher’s hands; the second group was taught by using applications including perspective drawings of concrete models; and the third group had the opportunity to examine concrete models by playing with them in their own hands. Weidemann reported that those students who did perspective studies and examined concrete models in their hands did better in spatial ability tests than the students who examined concrete models in their teacher’s hands. In a study conducted with students of faculty of engineering, Alias, Black and Gray (2002) investigated the effect of dynamic concrete objects and drawing activities on spatial ability by using a pretest posttest control group design. Results revealed that the experimental group students, who learnt in a constructivist atmosphere by moving objects and drawing the images which they imagined, had better post-test average scores than the control group students, who were taught in a traditional classroom environment.

Concrete models are known to have contributed to teaching of mathematics and spatial ability for centuries (Szendrei, 1996). On the other hand, these instructional tools started to be compared with dynamic software emerging in line with the recent development of computer technology. A particularly popular topic of research in this sense is whether concrete models or visual models within computer software are more effective in developing spatial ability (Baki, Kösa & Güven, 2011; Karakuş & Peker, 2015).

The NCTM (2000) reports emphasize that technological tools such as calculators and computers are basic tools of mathematics teaching and these tools provide students with opportunities to see the visual depictions of abstract concepts in mathematics, to easily edit and analyze data, and to perform calculations correctly. This standpoint was corroborated by many experimental studies, results of which revealed that use of appropriate instructional technologies, especially dynamic software tools, contribute to mathematical achievements and also geometrical thinking skills of students at different class levels (Güven, 2012; Olkun, Altun & Smith, 2005; Olkun, 2003). On the other hand, NCTM (2000) reports indicate that there is a need to use visual technologies for development of spatial skills in geometry education. Hence, in recent years, many researchers also examined the role of various computer-aided applications in developing spatial ability.

Güven and Kösa (2008) investigated the impact of geometry activities carried out with Cabri 3D software on preservice elementary mathematics teachers' spatial skills. The results identified a significant increase in the sample’s spatial ability scores after applications. In another experimental study, Cohen and Hegarty (2008) investigated the impact of interactive computer animation prepared in Virtual 3D software and spatial visualization activities with visual geometric objects on the spatial visualization levels of university students with low spatial ability. The activities in that study were about imagining and drawing cross-sections of 3D objects. They determined that the students’ skills to visualize objects’ cross-sections improved significantly as a result of the exercises. In another study, Sorby and Baartmans (2000) planned a computer-aided course to develop the skills of engineering students with low 3D spatial visualization skills. Consisting of activities such as transformations of objects, drawing cross-sections, opening and closing of surfaces, the course used software called I-DEAS as a visualization tool. The results from Sorby and Baartmans’ study showed that the participants’ spatial ability scores increased significantly. In addition to studies that examine the effectiveness of computer-aided applications, Baki et al. (2011), Karakuş and Peker (2015) compared the effects of using dynamic geometry software and using concrete materials in teaching geometric solids on the spatial skills of preservice elementary mathematics teachers. In the study, there were two experimental groups and one control group; one of the experimental groups was taught using dynamic geometry software, the other experimental group was taught about geometric solids using concrete materials applications, but the control group was taught using traditional methods. The results revealed that the group using software made the most progress in spatial ability.

While the effectiveness of a lot of different dynamic geometry software, visual manipulatives and computer games in teaching spatial ability is tested, some recent studies have suggested that GSU, which is a 3D modeling software used in the field of engineering and architecture, might contribute to the development of spatial ability due its properties (Fleron, 2009; La Ferla et al., 2009; Scarpino, 2010; Turğut & Uygan 2014). Fleron (2009) argued that GSU software would (a) facilitate examination of properties of geometric objects, (b) allow for creating any kind of geometric structure by means of its toolkit, (c) facilitate teaching perspectives by providing different views of structures by means of the ‘camera’ button, (d) facilitate learning transformation geometry and the concept of symmetry by means of ‘shapes rotation’ feature, and (e) allow for better comprehension of cross-sections of objects by means of ‘extracting cross-sections’ feature. Fleron (2009) suggested that all these features make GSU a very powerful technological tool in teaching spatial ability. In an experimental study conducted with junior-high school students, La Ferla et al. (2009) aimed to investigate the effect of dynamic 3D models formed in GSU on students’ levels of understanding 3D structures in the United States and Turkey. In La Ferla et al.’s (2009) study, the experimental and control groups in both of the countries were involved in some activities and the experimental groups did activities about building and examining 3D structures in a dynamic way. La Ferla et al. (2009) found that the teaching activities significantly affected the students’ spatial skills in both of the countries. Results showed that GSU could be used as an alternative tool to develop spatial ability.

2. Method

This was an experimental study. The independent variables of the study were 3D modeling software and concrete model-aided teaching activities. The dependent variables were the four separate skills within spatial ability: “to visualize cross-sections of an object”, “to visualize an object based on its surface development”, “to mentally rotate an object”, and “to visualize different views of an object”. The study used a pretest posttest control group design. There were two experimental groups and one control group in the study: the GSU group studied with Google SketchUp, the CM group studied with concrete models, and the control group studied with traditional teaching tools.

2.1. Study Sample

The study was carried out with a total of 72 preservice elementary mathematics teachers taking Geometry course at a state-funded university in Turkey. There were 24 participants in the GSU experimental group, 24 participants in the CM experimental group and 24 participants in the control group.

2.2. Measurement Tools

The Santa Barbara Solids Test (SBST) and the Purdue Spatial Visualization Test (PSVT) were used to measure the participants’ different spatial skills. The SBST was developed by Cohen and Hegarty (2007) to measure the ability to visualize cross-sections of 3D shapes. The test consists of 30 multiple choice items including various 3D shapes cut by horizontal, vertical or oblique plane (see Figure 1) and asking cross-sections of 3D shapes formed by the cutting.

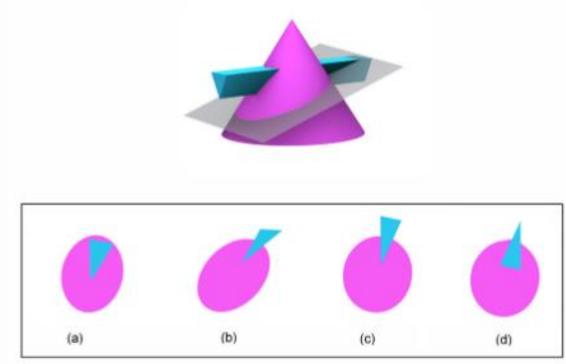


Figure 1. A sample item in the SBST

Before administering the SBST, the instructions for the test were translated from English into Turkish by the researchers. Then Turkish, English and Mathematics subject matter experts were asked to review the translated instructions. In order to test reliability, the test was first administered to 122 university students, the collected data were then analyzed with KR reliability analysis and the reliability coefficient of the test was found as 0.84. On the other hand, while developing the SBST, Cohen and Hegarty (2007) determined the Cronbach Alfa reliability coefficient of the test as 0.86 and considered the test reliable.

In order to measure the skills related to spatial ability – “to visualize an object based on its surface development”, “to mentally rotate an object”, and “to visualize different views of an object– the Purdue Spatial Visualization Test (PSVT), which was developed by Guay (1976, as cited in Scribner, 2004) consists of 36 multiple choice items, was used in this study. The PSVT consists of three parts, each of which contains 12 items: Developments, Rotations, and Views. The instructions in these three parts were translated from English into Turkish by the researchers and then Turkish, English and Mathematics subject matter experts were asked to review the translated instructions.

The Developments part includes the first 12 questions of the PSVT, which were designed to measure the ability to “visualize an object based on its surface development”. This skill is related to spatial visualization. In each of the items in this part, students are expected to identify 3D object to which the given surface developments belong when the scanned surface is taken as the base. Figure 2 shows a sample item in this part.

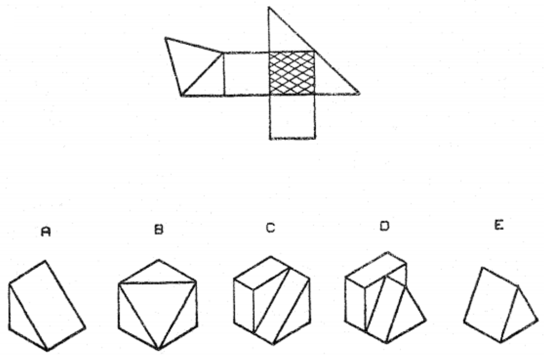


Figure 2. A sample item in the Developments part of the PSVT

The second part of the PSVT, "Rotations", measures the ability to "mentally rotate geometric objects". This skill is related to spatial relations. The items in the Rotations part presents with a sample rotation first. That sample shows the position of a 3D geometric object after it is rotated with a certain manner. Then students are asked to choose the correct position of an object among five choices when the object is rotated in exactly same manner. Figure 3 shows a sample item in this part.

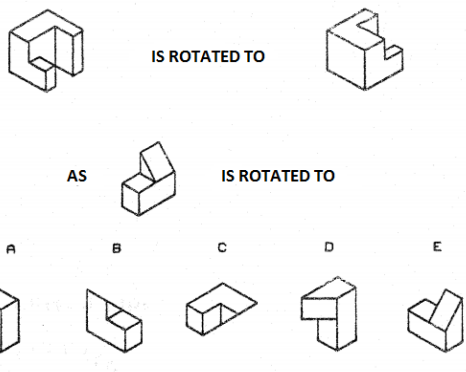


Figure 3. A sample item in the Rotations part of the PSVT

The last part of the PSVT, "Views", measures the ability "to visualize different views of an object". This skill is related to spatial orientation. In the items of the Views part, a geometric object is positioned in the middle of a glass box (cube) and one of the corners of the box is marked with a black dot (see Figure 4). Students are asked to choose among five choices how the geometric object would look when they look from the corner marked. Figure 4 shows a sample problem in the Views part.

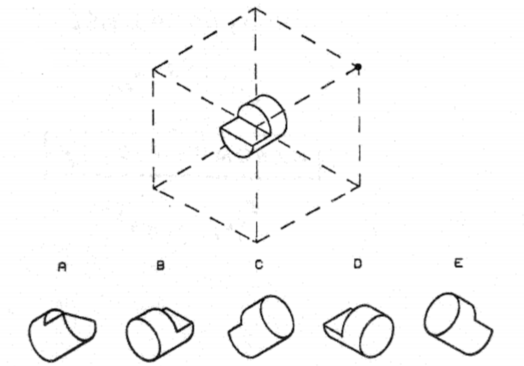


Figure 4. A sample item in the Views part of the PSVT

In order to determine the reliability in the study, the PSVT was administered to 181 university students and the reliability coefficient of the test was calculated as 0.84 as a result of the KR-20 reliability analysis. Regarding the analyses for the parts in the PSVT, the reliability coefficients for the Developments, Rotations and Views parts were found as 0.67, 0.69 and 0.66, respectively.

2.3. Implementation process

During the experimental process, the three groups were involved in problem-based activities about geometric solids. For these activities, the three groups were given the same worksheets. However, the GSU group analyzed the 3D objects in the problems using GSU and the CM group used concrete modeling. On the other hand, the control group examined the objects through their planar representations on paper. Table I shows the common implementation schedule planned in accordance with the contents of the subject of geometric solids.

Table 1. Implementation schedule

Week	*Content*	*Explanation*
Week 1	Implementation of the pretests and explanations regarding the learning process	Implementation of the SBST and PSVT as pretest; informing preservice teachers about learning process and content of the activities.
Week 2	Activities about prisms and pyramids	Exploring and implementing solution ways about different problems about the volumes and cross-sections of prisms and pyramids

Table 1 continued

Week 3	Activities about prisms, cylinders, and pyramids	Exploring and implementing solution ways about different problems about the volumes, surface areas and cross-sections of prisms, cylinders, and pyramids
Week 4	Activities about cylinders and cones	Exploring and implementing solution ways about different problems about the volumes and surface areas of cylinders, and pyramids
Week 5	Activities about prisms, pyramids, and cones	Performing surface developments of objects consisting of prisms and solving problems about building prisms and pyramids based on their surface developments; solving problems about the surface development and surface area of cones
Week 6	Activities about cylinders, cones, and spheres	Exploring solution ways for problems about the surface development and surface area of cylinders and cones and for problems about the volumes and cross-sections of spheres
Week 7	Implementation of the posttests	Implementation of the SBST and PSVT as posttest

In the first week of the implementation process, after the pretests were implemented, the GSU group were introduced to the toolkit of GSU in a computer lab and they did exercises about the use of each of the tools. In the following weeks, the preservice teachers completed the worksheets about geometric objects as stated in the schedule. For the problems in the worksheets, the preservice teachers saw the planar illustrations of the shapes on paper and, while developing solution ways for the problems, they analyzed the properties of the objects on the GSU models (see Figure 5). At this stage, the preservice teachers looked at the shape from different viewpoints by rotating the models on computer, investigated the relations between the objects, made drawings on them, broke the shapes into parts and closed their surface developments. The teacher (researcher) provided support for the preservice teachers who experienced difficulties in using software toolkit using the first few weeks. Also, in pairs, the preservice teachers were involved in discussions about the ways to solve the problems.

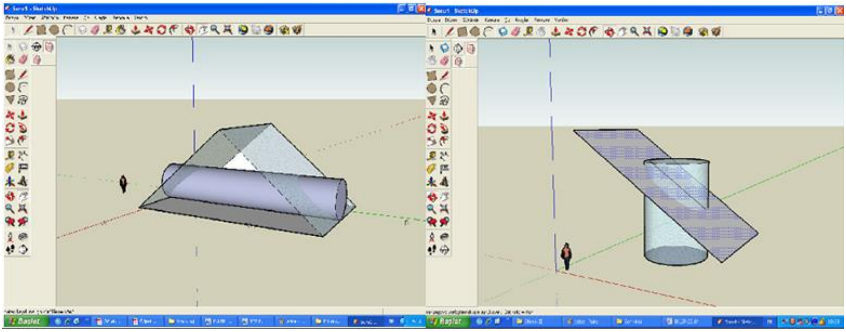


Figure 5. GSU models used in the activities

The preservice teachers in the CM group examined the problems in the same worksheets in accordance with the schedule but by using concrete models. The concrete models used in the implementation process consisted of MoNE's teaching models and the products made by the researcher with plastic materials and paperboard (see Figure 6).

Figure 6. Concrete models used in the activities

The preservice teachers used the models in turns because there was not a concrete model for each of them for the activities. At times, however, the activities were carried out in groups. Unlike the preservice teachers in the other groups, the control group participants examined the problems only through their representations on paper. This group used traditional teaching tools such as paper, pencil and classroom writing board. At times, the teacher (researcher) explained a problem by drawing the corresponding paper representation on the board. Also, the preservice teachers in the control group formed three-person groups and took part in discussions about the solution of the problems. Figure 7 shows a sample problem in the worksheets delivered to the groups.

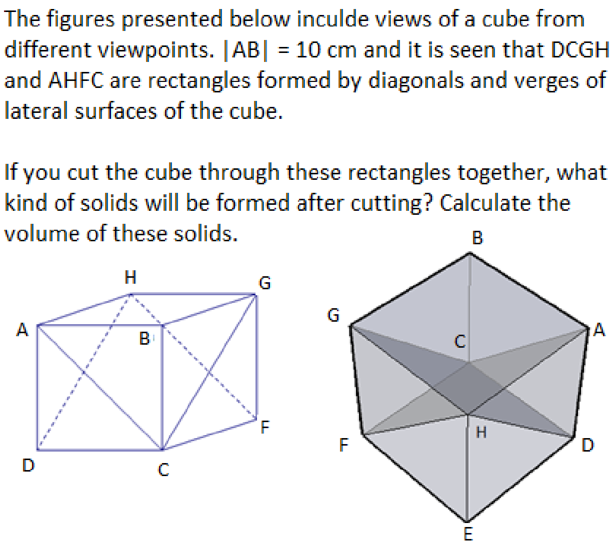
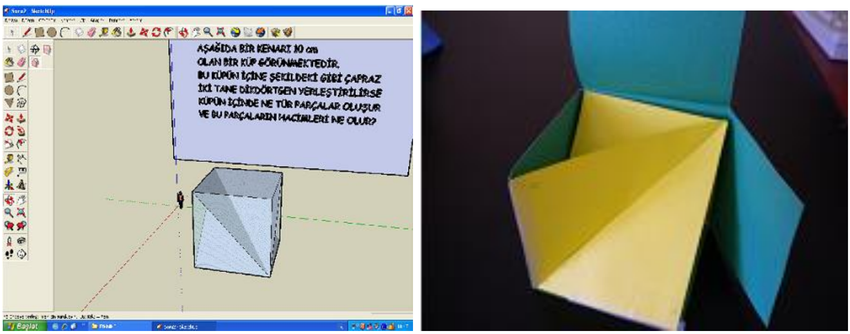


Figure 7. A sample problem in the worksheets delivered to the three groups

Figure 8 shows two separate models used by the GSU and CM groups about the problem given in the Figure 7.



(a) (b)

Figure 8. (a) The GSU model, (b) the concrete model about the problem.

In parallel to the problem solving activities, the preservice teachers in the GSU group were assigned a performance homework which they were supposed to do using the software. For this assignment, by working in groups of three people, the preservice teachers were required to build a site area in GSU and design structures with extraordinary geometric properties to be located in this area. They were also asked to estimate and report on the site sketch, the geometric names of the structures, their surface developments, surface areas and volumes. In the final week, as a part of the assignment, the preservice teachers made presentations about the products which they prepared in GSU (see Figure 9). Following the presentations, the products were assessed and the posttests were administered to the preservice teachers.

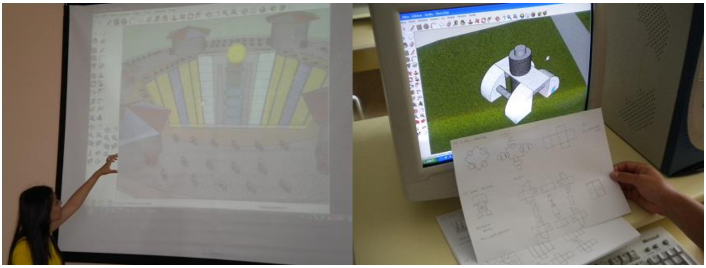


Figure 9. Presentation of the performance assignment products of the GSU group

A similar performance assignment with the same tasks was also assigned to the CM group, but, unlike the GSU group, this group were required to build the structures based on concrete models. During the process, various materials such as carton, paperboard, and plastic industrial products were used to build structures. Also, the CM group were required to report on the structures' sketches, surface developments, surface areas and volumes. In the final week, the CM group made presentations in the classroom about their performance assignments, too (see Figure 10).

Figure 10. Presentation of the performance assignment products of the CM group

2.4. Data analysis

The first step in analyzing the data obtained from the spatial ability tests was to investigate whether the pretest and posttest scores were distributed normally. In this regard, the pretest and posttest scores of the SBST, PSVT-overall, "Developments", "Rotations" and “Views” were tested with the Kolmogorov-Smirnov test. This analysis showed that the p significance values for the score averages except for the SBST pretest were lower than 0.05. For this reason, non-parametric tests were used to compare and contrast the score averages of the groups (Altunışık, Coşkun, Bayraktaroğlu & Yıldırım 2010; Baştürk, 2010). The Kruskal Wallis test was used to perform multiple comparisons of the groups, the Mann Whitney U test was used to compare and contrast groups in pairs and the Wilcoxon test was used to compare and contrast the pretest and posttest scores of each of the groups.

3. Findings

This part of the study presents the results of the analyses on the scores of spatial ability tests. Table 2 shows the results of the Kruskal-Wallis Test carried out on the pretest scores for the SBST, the PSVT-overall, Developments, Rotations and Views.

Table 2. Kruskal-Wallis test results on the pretest scores of the groups

	Groups	***n***	$\overline{X}$	***SD***	***Kruskal Wallis*** χ^2	***Df***	***p***
SBST	GSU	24	13.37	6.09	0.552	2	0.759 $p > 0.05$
	CM	24	14.75	7.51			
	Control	24	13.41	4.62			
PSVT Total	GSU	24	15.12	5.65	1.251	2	0.535 $p > 0.05$
	CM	24	16.70	6.32			
	Control	24	15.20	5.45			
Developments	GSU	24	4.50	2.28	0.339	2	0.844 $p > 0.05$
	CM	24	4.95	2.54			
	Control	24	5.00	2.28			
Rotations	GSU	24	5.33	2.61	2.967	2	0.227 $p > 0.05$
	CM	24	6.20	2.48			
	Control	24	5.12	2.23			
Views	GSU	24	5.29	2.62	0.408	2	0.815 $p > 0.05$
	CM	24	5.54	2.73			
	Control	24	5.08	2.60			

According to Table 2, there was not a difference among the pretest scores of the groups at a significance level of 0.05. This result shows that the spatial ability scores the three groups were at the same level.

Table 3 shows the results of the Kruskal-Wallis Test carried out to see whether there was a significant difference among the post-test scores of the three groups.

Table 3. Kruskal-Wallis test results on the posttest scores of the groups

	Groups	***n***	$\overline{X}$	***SD***	***Kruskal Wallis*** χ^2	***Df***	***p***
SBST	GSU	24	18.8	6.16	4.559	2	0.102 $p > 0.05$
	CM	24	17.6	6.61			
	Control	24	15.8	4.73			
PSVT Total	GSU	24	20.5	6.59	3.435	2	0.180 $p > 0.05$
	CM	24	19.2	7.29			
	Control	24	16.8	6.75			
Developments	GSU	24	6.41	2.55	0.427	2	0.808 $p > 0.05$
	CM	24	6.70	2.72			
	Control	24	6.20	3.03			
Rotations	GSU	24	6.75	2.92	1.288	2	0.525 $p > 0.05$
	CM	24	6.91	3.02			
	Control	24	6.12	2.52			
Views	GSU	24	7.37	2.53	13.078	2	0.001 $p < 0.05$
	CM	24	5.58	2.90			
	Control	24	4.54	2.16			

According to Table 3, there was not a difference at a significance level of 0.05 among the posttest scores of the groups for the SBST, PSVT-overall, Developments and Rotations. However, there was a difference at a significance level of 0.05 among the Views part posttest results. Table 4 shows the results of the Mann Whitney U Test which was carried out to determine between which groups this difference existed.

Table 4. The Mann Whitney U test results on the posttest scores in the Views part of PSVT

Groups	***Mean Difference***	***Z***	***U***	***p***
GSU - CM	1.79	-2.171	183.5	0.03 $p < 0.05$
GSU - Control	2.83	-3.681	111.0	0.000 $p < 0.05$
CM - Control	1.04	-1.135	233.5	0.256 $p > 0.05$

According to Table 4, the “Views” posttest scores of the GSU group were higher than those of the CM and the control group at a significance level of 0.05. On the other hand, there was not a significant difference between the scores of the CM and the control groups.

The Wilcoxon test was used to compare and contrast the pretest and posttest scores in the spatial ability tests of the groups separately. Table 5 shows the Wilcoxon test results on the groups' pretest and posttest scores for the SBST.

Table 5. Comparison of the SBST pretest-posttest scores

Group	*Pretest– Posttest Mean Difference*	*Ranks*	*n*	*Mean Ranks*	*Sum of Ranks*	*Z*	*p*
		Negative	6	9.25	55.5	-2.704	0.007
GSU	-5.4583	Positive	18	13.58	244.5		p < 0.05
		Equal	0				
		Total	24				
		Negative	6	11.42	68.5	-2.120	0.034
CM	-2.9167	Positive	17	12.21	207.5		p < 0.05
		Equal	1				
		Total	24				
		Negative	9	9.61	86.5	-1.570	0.116
Control	-2.4583	Positive	14	13.54	189.5		p > 0.05
		Equal	1				
		Total	24				

According to Table 5, the SBST posttest average scores of both the GSU and the CM groups were higher than the pretest average scores at a significance level of 0.05. However, there was not a significant difference at a level of 0.05 between the SBST pretest and posttest scores of the control group. Table 6 shows the results of the Wilcoxon test that was carried out to compare and contrast the PSVT pretest and posttest scores of the three groups.

Table 6. Comparison of the PSVT pretest-posttest scores

Group	*Pretest– Posttest Mean Difference*	*Ranks*	*n*	*Mean Ranks*	*Sum of Ranks*	*Z*	*p*
		Negative	4	11.63	46.5	-2.959	0.003
GSU	-5.4167	Positive	20	12.68	253.5		p < 0.05
		Equal	0				
		Total	24				
		Negative	8	10.69	85.5	-1.847	0.065
CM	-2.5000	Positive	16	13.41	214.5		p > 0.05
		Equal	0				
		Total	24				
		Negative	7	10.86	76.0	-1.898	0.058
Control	-1.6666	Positive	16	12.5	200.0		p > 0.05
		Equal	1				
		Total	24				

According to Table 6, the PSVT posttest scores of the GSU group were higher than their posttest score at a significance level of 0.05. However, there was not a significant difference between the pretest and posttest scores of both the CM group and the control group. On the other hand, the p significance levels for these two groups were very close to 0.05. Table 7 shows the results of the Wilcoxon test comparing the pretest and posttest scores of the groups for the "Developments" part in the PSVT.

Table 7. Comparison of the pretest-posttest scores in the "Developments" part of PSVT

Group	*Pretest–Posttest Mean Difference*	*Ranks*	*n*	*Mean Ranks*	*Sum of Ranks*	*Z*	*p*
GSU	-1.9167	Negative	4	8.88	35.5	-2.974	0.003
		Positive	18	12.08	217.5		$p < 0.05$
		Equal	2				
		Total	24				
CM	-1.7500	Negative	3	8.5	25.5	-2.813	0.005
		Positive	16	10.28	164.5		$p < 0.05$
		Equal	5				
		Total	24				
Control	-1.2083	Negative	4	16.0	64.0	-2.269	0.023
		Positive	19	11.16	212.0		$p < 0.05$
		Equal	1				
		Total	24				

As can be seen in Table 7, the posttest scores of each of the groups were higher than their pretest scores separately at a significance level of 0.05. Table 8 shows the results of the Wilcoxon test comparing the pretest and posttest scores of the groups for the "Rotations" part in the PSVT.

Table 8. Comparison of the pretest-posttest scores in the "Rotations" part of PSVT

Group	*Pretest–Posttest Mean Difference*	*Ranks*	*n*	*Mean Ranks*	*Sum of Ranks*	*Z*	*p*
GSU	-1.4167	Negative	6	10.92	65.5	-1.990	0.047
		Positive	16	11.72	187.5		$p < 0.05$
		Equal	2				
		Total	24				
CM	-0.7083	Negative	6	11.0	66.0	-1.784	0.074
		Positive	15	11.0	165.0		$p > 0.05$
		Equal	3				
		Total	24				
Control	-1.000	Negative	7	9.36	65.5	-1.761	0.078
		Positive	14	11.82	165.5		$p > 0.05$
		Equal	3				
		Total	24				

According to Table 8, the posttest scores of the GSU group in the "Rotations" part were higher than the pretest scores in the same part at a significance level of 0.05. On the other hand, the p significance value which was found by comparing the scores of the GSU group was lower than 0.05 but it was very close to it ($p = 0.047$). However, there was no significant difference between the pretest and posttest scores of both the CM group and the control group.

Table 9 shows the results of the Wilcoxon test that was carried out to see whether there was a statistically significant difference between the pretest and posttest scores of the groups for the "Views" part in the PSVT.

Table 9. Comparison of the pretest-posttest scores in the "Views" part of PSVT

Group	*Pretest–Posttest Mean Difference*	*Ranks*	*n*	*Mean Ranks*	*Sum of Ranks*	*Z*	*p*
		Negative	6	9.50	57.0	-2.473	0.013
GSU	-2.0833	Positive	17	12.88	219.0		$p < 0.05$
		Equal	1				
		Total	24				
		Negative	9	11.56	104.0	-0.038	0.970
CM	-0.0417	Positive	11	9.64	106.0		$p > 0.05$
		Equal	4				
		Total	24				
		Negative	13	9.85	128.0	-1.354	0.176
Control	0.5417	Positive	6	10.33	62.0		$p > 0.05$
		Equal	5				
		Total	24				

According to Table 9, the posttest score average of the GSU group for the "Views" part was higher than their pretest average at a significance level of 0.05. However, there was not a difference between the pretest and posttest scores of the CM group for the same part at a significance level of 0.05. On the other hand, the posttest score average of the control group in this part was unexpectedly lower than their pretest average, but this difference was not significant at a level of 0.05.

4. Conclusion and Suggestions

This study explored the training activities carried out with GSU, concrete models, and traditional instructional tools such as drawings of 3D objects on the paper, within geometric solids on preservice elementary mathematics teachers' spatial skills. In the study, the SBST was used to measure the skill "to visualize cross-sections of an geometric solid" while the "Developments", the "Rotations" and the "Views" parts in the PSVT were used to measure the skills "to visualize a geometric solid based on its surface development", "to mentally rotate an geometric solid", and "to visualize different views of a geometric solid", respectively. The activities supported by GSU significantly improved the scores related to these four skills whereas the activities designed with concrete models improved the SBST and the "Developments" part scores and the activities performed on traditional tools improved only the "Developments" part scores. Also, comparison of the posttest scores of the groups showed that the activities aided by GSU were more effective on the skill "to visualize different views of a geometric solid" more than activities carried out on concrete models and traditional tools. On the other hand, comparison of the scores related to the other spatial skills determined no significant difference among the groups. At this point, further long termed research might be carried on to examine differences of training methods deeply.

However, in this study, the most effective teaching activities in developing spatial skills were those supported by GSU, but the least effective teaching activities were the ones carried out on traditional tools. Similarly, Cohen and Hegarty (2008) found that the cross-section activities in Virtual 3D, another 3D computer software, significantly increased the university students' SBST scores. Also, Sorby and Baartmans (2000) found that computer-aided applications significantly increased the Mental Cutting Test scores of the university students with low 3D spatial visualization ability. In this sense, this result of the study is supported by the results of the studies by Cohen and Hegarty (2008) and Sorby and Baartmans (2000).

This study also found that the teaching activities supported by GSU significantly improved the scores related to the skill "to visualize a geometric solid based on its surface development". According to the definitions of the components of spatial ability, this skill belongs to spatial visualization skill (Linn & Petersen, 1985; Lohman, 1988; Carroll, 1993; Maier, 1998; McGee, 1979; Olkun & Altun, 2003; Sorby, 1999). Therefore, it could be suggested that the teaching activities supplemented by GSU were effective in developing spatial visualization in this study. This result is similar to the results obtained by Baki et al. (2011), Dorta, Saorin and Contero (2008), La Ferla et al. (2009) and Olkun et al. (2009).

In this study, the teaching activities supported by GSU in teaching geometric solids significantly increased the preservice teachers' scores related to the skill "to mentally rotate a geometric solid". Carroll (1993), Maier (1998), and Olkun and Altun (2003) defined the skills about "mentally rotating 2D and 3D shapes" as spatial relations. According to this definition, it is possible to effectively use the teaching activities in this study in spatial relations training. Baki et al. (2011), Dorta, Saorin & Contero (2008), Turğut (2010) and Yıldız (2009) stated that similar teaching activities using 3D computer software promoted this ability as well. In this sense, this result of the study is similar to the results of other similar studies in the literature.

In addition, it could be suggested that the GSU-aided teaching activities used in teaching geometric solids significantly increased spatial orientation, which is the skill "to visualize different views of a geometric solid". In fact, the GSU-aided activities in this study were more effective on this skill more than the CM-aided activities and traditional teaching.

Similarly, Baki et al. (2011) and Güven and Kösa (2008) found that activities carried out with 3D dynamic geometry software improved this skill better than concrete manipulatives and traditional teaching methods. In this regard, the results of these studies support each other. Therefore, it could be suggested that GSU software could be a good alternative to other technologies in developing spatial ability.

The results about the teaching activities supported by CM showed that the preservice teachers' spatial visualization skills improved. However, the improvement of spatial relations and spatial orientation skill was not at the desired level. These results show that the CM-aided teaching activities were effectively used in developing spatial visualization but the desired level of improvement couldn't be achieved in developing spatial relations and spatial orientation. Bayrak (2008) found that visual methods including concrete models, manipulative and origami activities significantly increased 6th grade students' SA test scores related to paper folding and visualizing objects based on their surface developments. In this sense, the result of Bayrak's (2008) study is similar to this study's results. On the other hand, Baki et al.'s (2011) and Karakuş et al.'s (2015) study found that the groups using software and concrete models in their study received higher posttest scores in the PSVT, "Developments", "Rotations" and "Views" parts than the control group. This result of Baki et al.'s (2011) and Karakuş et al.'s (2015) study has difference with this study in the context of effectiveness of CM-aided teaching on spatial relations and spatial orientations. This difference might have been associated with that number of the concrete models for per participant and the contents of the CM-aided teaching activites in this study differs from other studies. In this regard, the fact that, in this study, there was not one each concrete model for the participants, the concrete models were used by the participants in turns. Therefore, it could be considered as a limitation of this study.

Some recommendations were made in the light of the results obtained for researchers, faculty members and teachers. Considering the fact that the teaching activities supported by GSU had a positive effect on preservice elementary mathematics teachers' spatial skills, similar teaching activities can be used as an alternative method for developing various spatial skills. Also, by designing studies about the use of 3D modelling software in mathematics teaching methods for elementary mathematics education degrees, preservice teachers could be equipped with necessary knowledge and skills to use the software as a teaching tool effectively. This study did investigate effects of certain applications on preservice teachers' spatial ability, but it did not investigate how the test scores were affected by some variables such as gender, level of computer literacy and achievement in geometry. For this reason, future research could investigate how similar teaching activities might affect the spatial skills of students at different levels based on these variables.

This study investigated the effect of teaching activities supported by GSU and concrete models on spatial abilities of students in higher education. Future studies could be conducted with similar teaching activities with students in elementary and secondary education. Gutierrez (1992) suggested that activities involving computer applications, concrete model and planar illustrations in teaching space geometry are interrelated and they can be employed in teaching in a way supplementing each other. In this regard, future studies could seek the ways to effectively use the three methods together.

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Citation Information

Uygan, C. & Kurtuluş, A. (2016). Effects of teaching activities via Google Sketchup and concrete models on spatial skills of preservice mathematics teachers. *Turkish Journal of Computer and Mathematics Education, 7*(3), 510-535.