

Spatial ability training for undergraduate mathematics education students: Designing tasks with SketchUp®*

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Abstract

The objective of this study was to design applications with SketchUp® software for undergraduate mathematics education students in order to improve their spatial skills. We prepared the activities using the software, and they consisted of two parts, each related to mental rotation and spatial orientation. The section related to mental rotation includes the application, which requires students to guess the visualization of the geometrical shapes according to given angles in three different axes, and the section related to spatial orientation includes the studies of the visualization of a three-dimensional object through different views and its isometric drawings. These studies were based on Guay's [7] Purdue Spatial Visualization Test's (PSVT) Rotations and Views sections and they are initial designs that will be included in a further experimental research project.

1. Introduction

Two of the reasons people need mathematics education are not only to help their problem-solving ability but also to help them understand and interpret the real world. For instance, one of the main fields of mathematics is geometry, which is related to the real world. Walking down a street, one can see geometrical objects everywhere, understand these objects, and even do personal analyses. However, one needs a different skill to be able to apprehend their location. This skill is called *spatial ability* or *spatial skill*. Here are two generic examples of this skill: (a) Imagine rotating a specific part of a Rubik's cube. Can you predict which shape you will see? (b) Imagine looking at a labyrinth from above and then entering on ground level. Can you remember the way out now entering from this other point of view? The answers to these questions have to do with your spatial ability. In the related literature, spatial ability is defined as moving and visualizing of an object's one or more parts in a three-dimensional space in the mind [26]. According to [17], two components of spatial ability are *spatial visualization*, which is moving, rotating, or inverting a given object, and *spatial orientation*, which is visualizing the given object as a result of looking at the object from a different perspective (view). The items that measure these skills and the ones that are most commonly used in the related literature are taken from *Purdue Spatial Visualization Test's* (PSVT) *Rotations* and *Views* parts and they are given in Figure 1 [7].

¹ A preliminary and shorter version of this paper was presented in *12. Mathematics Symposium* (23–25 May 2013) in Ankara–Turkey.

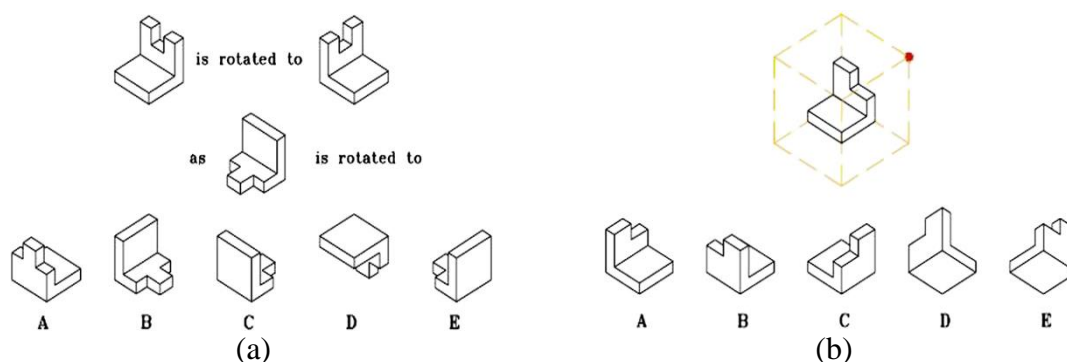


Figure 1: (a) Sample mental rotation task, (b) Sample spatial orientation task
(Reproduced from [14, p. 144])

One can see from examining Figure 1 that the spatial ability is measured through the manipulations of geometrical objects. In this respect, intuitively, it can be suggested that thinking spatially is related to mathematics achievement.

2. Spatial skills, Mathematics Education and Technology

Thanks to national and international studies, spatial ability terms (visualization, mental rotation, spatial perception, and visual ability) have been included in the curricula at every level of mathematics education. The reason is that there is commonly-known positive relation between spatial ability and mathematics-geometry success ([2], [12], [26]). For instance, in the revised Turkish elementary school mathematics curriculum, under the topic of geometrical objects, acquisitions and activities on the development of geometrical objects and surfaces are related to spatial visualization ability. Additionally, under the topic of geometrical objects and projection, acquisition of “draw different views of geometrical structures built by congruent cubes” is directly related to spatial orientation ability [31]. On the other side, in the curriculum of 9th – 11th grades of Ministry of National Education (MEB), spatial ability has found itself a place ([18], [19]). One of the general purposes of the curriculum is to enable “one [to] be able to improve navigational and spatial awareness, geometrical intuition and imagination,” which purpose aims for the direct improvement of spatial ability [31].

One of the most important characteristics of computers is their ability to fit the three-dimensional world onto a two-dimensional screen and to bring unique experiences to the user by engaging him or her in the visualization and imagination process. From the view of spatial ability, one’s unconscious process of imagination and visualization includes mentally rotating and visualizing from different perspectives pictures that may improve his or her spatial ability. Along with this, the National Council of Teachers of Mathematics (NCTM) [21] report stated that technological instruments might aid students to comprehend abstract concepts. The findings in the reviewed literature supported these hypotheses. It has been reported that some special applications (Web-based, Virtual Reality and Software applications) improve students’ spatial abilities. For instance, Rafi, Anuar, Samad, Hayati, and Mahadzir [24] implemented an experimental study using a Web-based Virtual Environment in order to enhance pre-service teachers’ spatial ability. The study was carried out through a computer-aided course which lasted for five weeks. Training and post-testing of spatial tests revealed, significantly, the participants’ overall spatial ability. Similarly, Kurtuluş and Uygan [15] investigated the effect of Google SketchUp®-based geometry activities and projects on spatial visualization skills of pre-service mathematics teachers. The experimental study revealed positive effects on spatial skills among the working group. Using another software, Turgut [27] investigated the effect of Mathematica©-based applications and isometric drawings in linear algebra courses on students’

spatial skills, and he found positive effects as well. For spatial orientation skills, Kurtulus [13] found similar results. Additionally, the reviewed literature also shows positive effects of virtual and map-based tours ([14], [25]), virtual reality applications ([8], [9]) and spatial games ([10]). Moreover, the activities that the students are involved in, such as isometric drawings, and forming models and perspective drawings are some suggestions of recent studies, and the authors stated that these applications will help students to improve their spatial skills ([13], [14], [22], [23], [27]).

In this study, we have prepared activities, which aim to improve students' spatial visualization and spatial orientation skills through SketchUp® software. An analysis of the psychometric tests that measure the spatial ability in the related literature, for instance PSVT [7], D'Costa Paper Folding Test [4], and tests of Surface Development, Card Rotation and Cube Comparison Tests [5], reveals that the test items are more related to rotating, analyzing, integrating, disintegrating, and visualizing images in the mind. Studies carried out in Turkey show that students from primary school to university have very low spatial abilities ([11], [12], [27], [28], [29], [32]). This study's purpose is to improve spatial ability through activities that can be added into their undergraduate curriculum for mathematics education.

3. The software, Context and Task Designs

3.1. SketchUp®

SketchUp® is a three-dimensional modeling software. Last Software developed its initial version in 2000, and Google bought its copyrights in 2006 when the software was more developed. Then Trimble bought the software in 2012. SketchUp® has been used in graphic design, in engineering, and in architectural fields as well as in three-dimensional modeling studies [20]. Moreover, recently, in the geometry part of the software, focus, patterns, transformations and the topics of improving the spatial ability have been added, all of which are part of the software's aim ([6], [15], [16], [30]). SketchUp® software's interface has axes in three-dimensional space and a human model for structure modeling and tools (Figure 2).

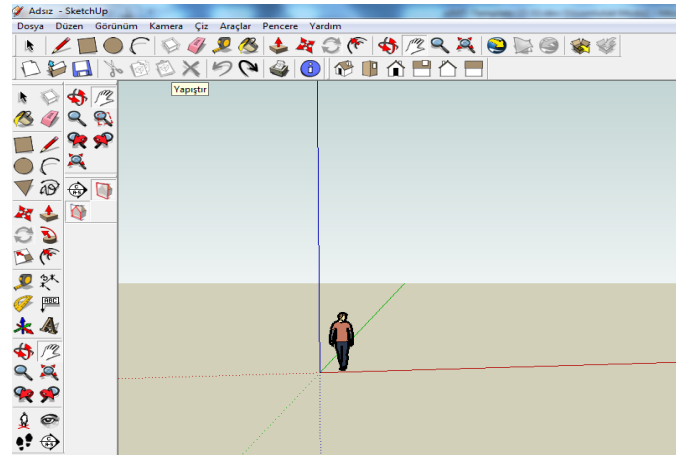





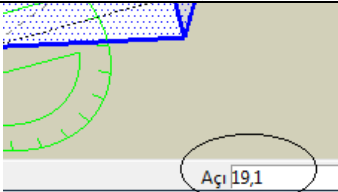


Figure 2: Interface view of SketchUp®.

The SketchUp® activities prepared in the scope of this study require using some important tools from the software. These tools and functions are expressed as in Table 1.

Table 1. *SketchUp® tools and their functions* [20].

SketchUp® Tools	Functions
 (Rotate)	Rotating an object by a certain angle according to axes.
 (Pan)	Scrolling view of screen horizontally or vertically.
 (Position Camera)	Positioning camera on a certain location to view objects on screen from there.
 (Look around)	Looking around at a certain point on the screen.
 (Orbit)	Rotating the whole screen to view objects from different viewpoints.
 (Measurement Control Box)	Providing feedback about length, height, and angle measurement while manipulating objects.

3.2. PSVT and Development of Activities

In this study, the reference point PSVT, was developed by Guay [7]. This test consists of three parts: *Developments*, *Rotations*, and *Views*, with 12 test items in each part. In the first part, *Developments*, the questions ask which one of the given closed options is the correct visualization of a three-dimensional object which was first shown as opened. In the *Rotations* part, the question asks what the images of the given objects are after they have been rotated mentally (Figure 1a). In the *Views* part, the questions ask how the given objects will look in different viewpoints (Figure 1b). The first part measures spatial visualization, the second part, mental rotation, and the third part, spatial orientation. In the related literature, this test is one of the most cited references in order to determine and measure students' spatial skills. For this reason, PSVT has been taken as a reference point.

In the preparation process of the activities, the following acquisitions are based on: At the end of the activity, students will be able to 1) visualize a given object from a different viewpoint, and 2) visualize an object by rotating it mentally. The applications, which aim to improve students' spatial ability through SketchUp®, have been designed as two separate activities for the skills of mental rotation and spatial orientation. The part about the mental rotation involves guessing the images of geometrical objects after rotating them in three different axes and drawing the isometric views of the images. The spatial orientation part involved visualizing geometrical structures in a cube and how they will be seen from their

separate corners and then drawing isometric views of the images. These activities have been designed according to PSVT’s *Rotations* and *Views* parts. The items in PSVT included the representation of three-dimensional objects on paper. In the activities, SketchUp®’s “camera” and “look around” tools (in the third and fourth line of the Table 1) were used for improvement of spatial orientation skill and “rotate” (in the first line of the Table 1) was used as an instrument (see [1]) to improve students’ mental rotation performance. In the activities, we provide the details about the tools for SketchUp® tasks and expected usage schemes the students are to use and how to use them (Table 2).

Table 2. *Design of the Activities*

Artefacts	Task	Expected Usage Scheme
<ul style="list-style-type: none"> • Look Around • Orbit 	<ul style="list-style-type: none"> • Education of Spatial Orientation (PSVT – Views) 	<ul style="list-style-type: none"> • Looking at 3D objects from specific points • Comprehending 3D environment
<ul style="list-style-type: none"> • Rotate • Measurement Control Box 	<ul style="list-style-type: none"> • Education of Mental Rotation (PSVT – Rotations) 	<ul style="list-style-type: none"> • Rotating 3D objects according to the axis • Entry of rotation degrees

The designed artifacts have enabled students to switch from 2D isometric drawing to 3D representations, and from that to isometric drawings. The examples, which correspond to PSVT items, are given in Figure 3.

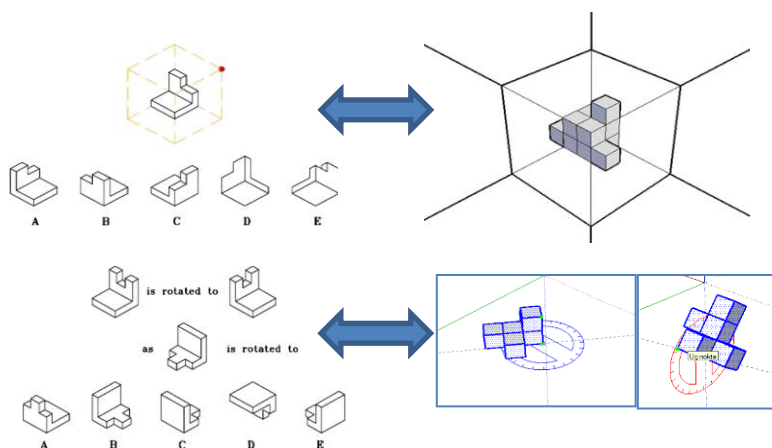


Figure 3: *SketchUp® models associated with PSVT items.*

Activity 1:

Task (1a): Below there is a SketchUp® model corresponding to an isometric representation (Figure 4). Can we have the image on the left when we take a look at the object from any angle? Where will this angle be?

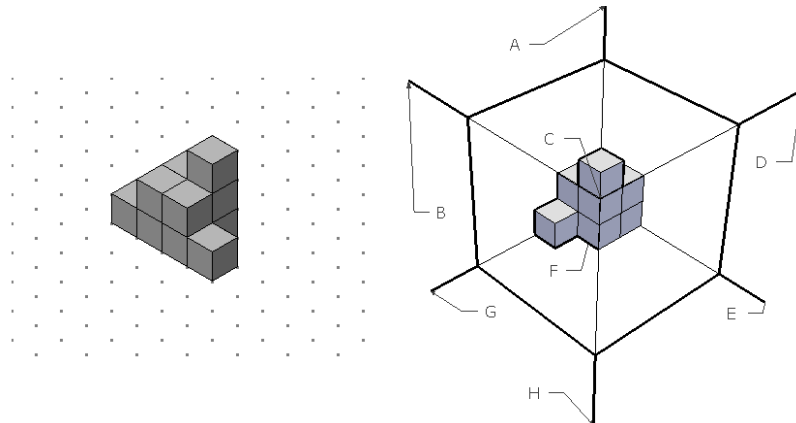


Figure 4: *Isometric representation of Task (a) and 3D model.*

In this process, students can be instructed to use the “camera” and the “look around” tools. In this stage, students can visualize the angles from each letter and through the camera tools, she or he can visualize the object’s images. Figure 5 summarizes this process.

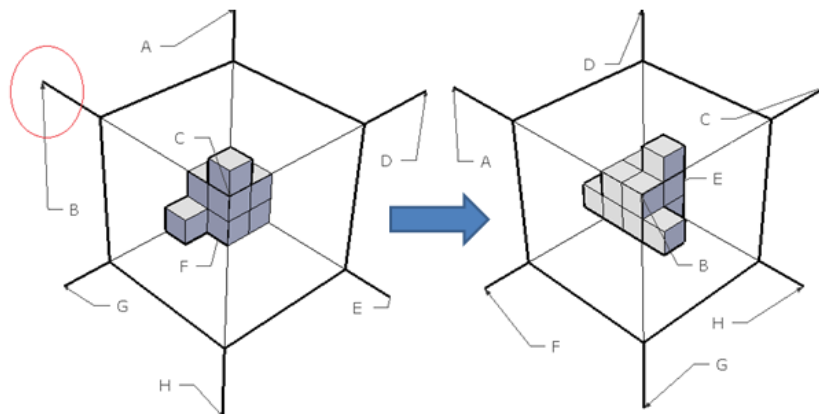


Figure 5: *Spatial orientation through camera tool.*

In the second part of the activity, students are asked to create their mental image that would be on point H on an isometric view after they look at the viewpoints from G and F. In this process, students use the “camera” tool again and they will create the visuals at points G and F, and then they will try to draw isometric views through the software. The desired image is given in Figure 6.

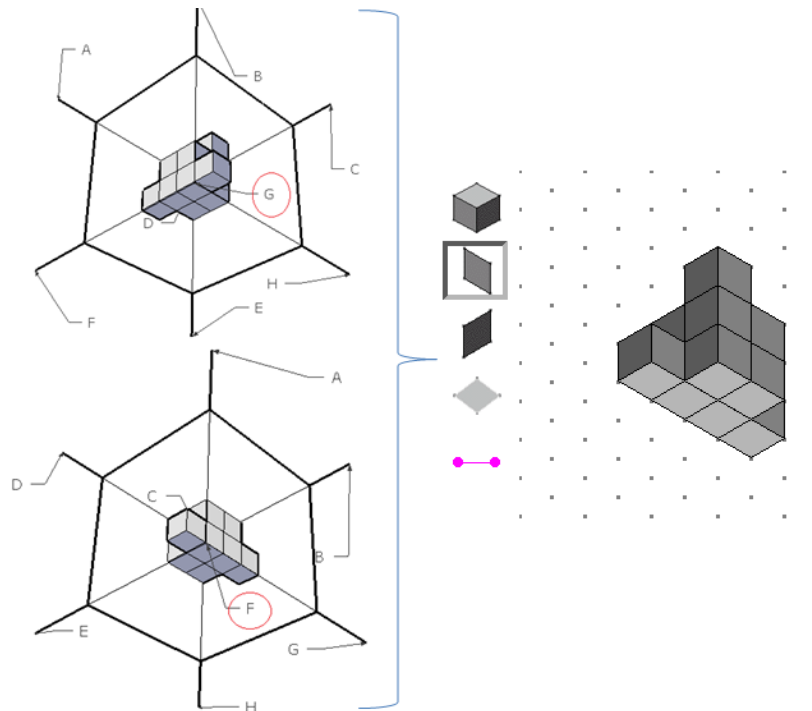


Figure 6: *Second step of the task (1a).*

Students are asked to do the same task on a different structure in SketchUp® (Figure 7).

Task (1b): When you look at the 3D structure on the right, can you get the isometric image on the left? Where might this viewpoint be?

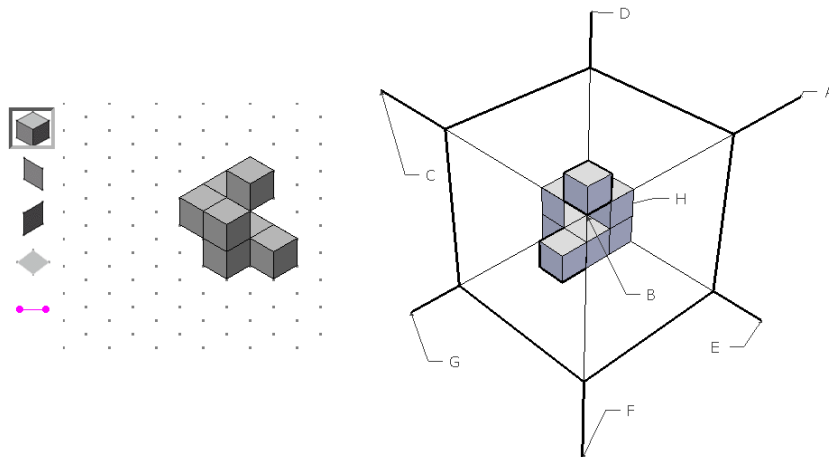


Figure 7: *Isometric representation and 3D model on task (1b).*

Look at this structure from point E, then look at it from point F, and then create the mental image on the isometric region. Students are expected to form the following figures (Figure 8).

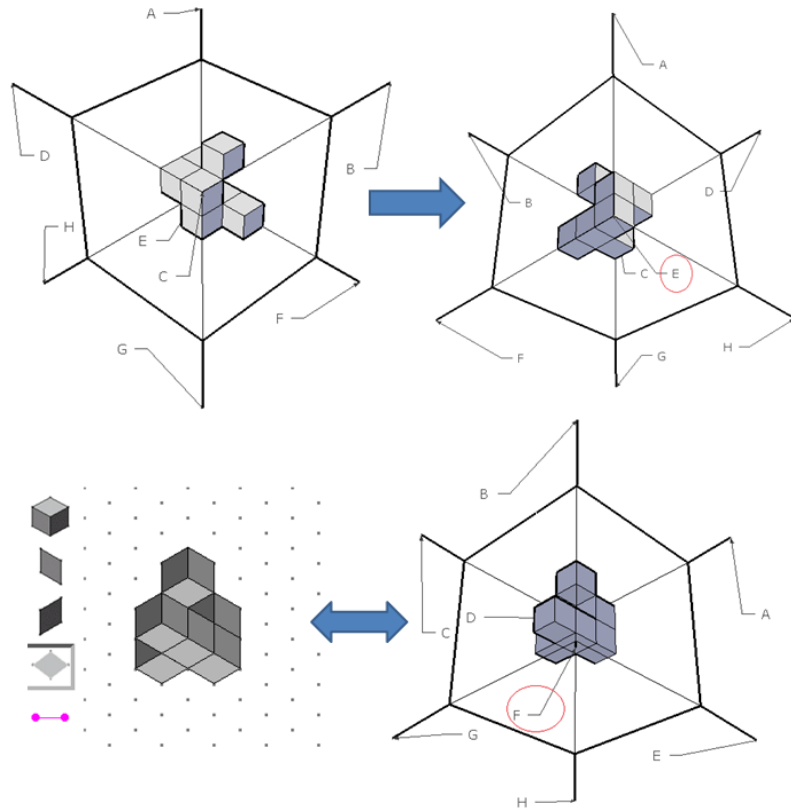


Figure 8: Steps expected to be applied by students at Task (b).

Activity 2:

Task (2a): For the 3D structure on the left to be the structure on the right, from which axis should it be rotated and by how many degrees? (see Figure 9).

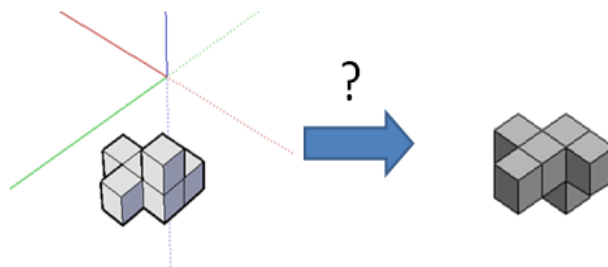


Figure 9: 3D models in Task (2a).

In this activity, students should use the “rotate” and “pan” tools. “Pan” is used to adjust the image the student needs to rotate. Furthermore, the control box gives feedback to the users while they use the rotating tool. In the rotating process, the protractor’s color shows the direction in which the image is rotating.

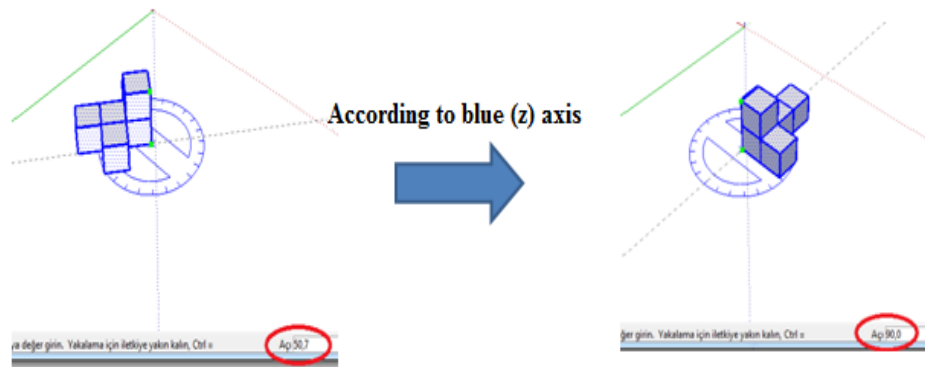


Figure 10: *Rotating in z-axis and feedback in control box in Task (2a).*

Students should get 90 degrees in the blue axis (z) of the 3D model in Task 2a and 180 degrees in the red axis of the model (Figure 10 & 11). After reaching the target, students are asked whether the order of the rotating will change the outcome or not.

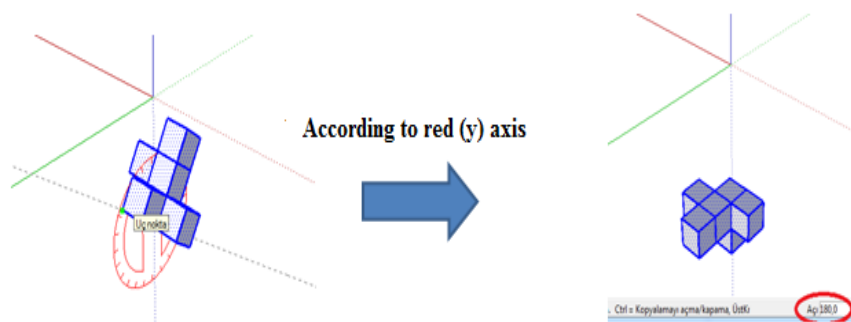


Figure 11: *The rotating towards y-axis and the feedback in control box in Task (2a).*

In the next process, students are asked to create the mental image on the isometric level after the image has been rotated 180 degrees on the green (x) axis, starting with the target image. This process aims to help the students mentally visualize the images. After creating the isometric representation, students check the result by rotating the 3D object using the software (Figure 12).

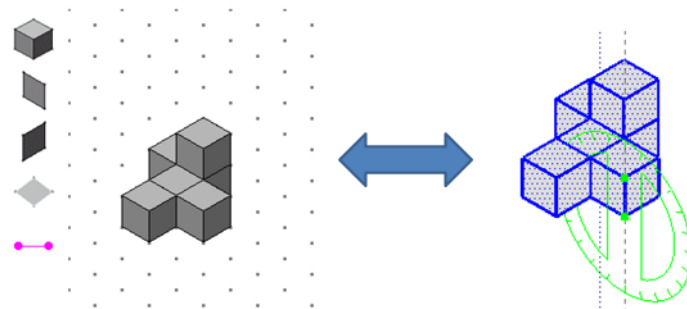


Figure 12: *Creating the isometric representation and evaluating the result in the software in Task (2a).*

Students are expected to do a similar activity on a different object.

Task (2b): For the 3D structure on the left to be the structure on the right, from which axis should it be rotated by how many degrees? (see Figure 13).

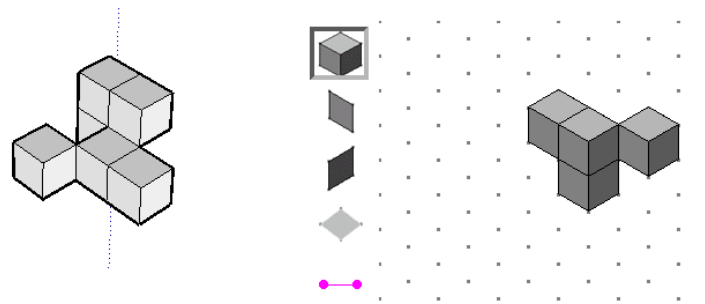


Figure 13: 3D models in Task (2b).

Students are expected to reach the target image by using the “rotate” and the “measurement control box” tools. The strategies are explained and how many degrees are needed according to the given axis.

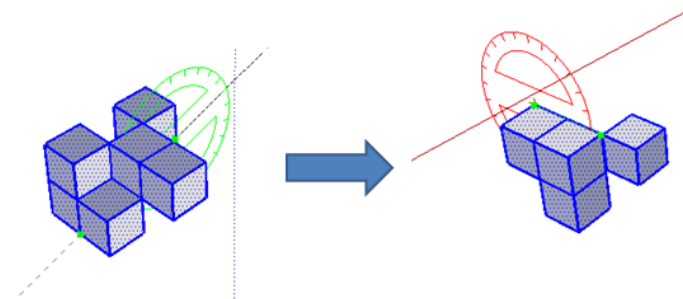


Figure 14: The solution process of the Task (2b) in the software.

Following the final image (Figure 14), students are asked to rotate the object 180 degrees on the blue (z) axis and to create the image on the isometric region. After the image is completed, they complete the final rotating using the software, and the result is evaluated (Figure 15).

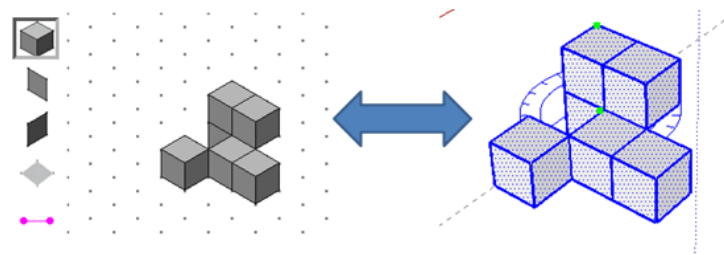


Figure 15: Creating the isometric drawings and evaluating the result on the software.

4. Conclusion and Further Remarks

For this study, activities that aim to improve undergraduate mathematics students’ spatial skills in mental rotation and spatial orientation have been designed. In the designing process of the activities, we used some special tools of a modeling software program, called SketchUp®. The activities presented in this study are the basic designs of an experimental research that will be included in a specific project entitled “Spatial ability training for mathematics education students”. These activities are parts of the experimental process that are related to spatial orientation training and mental rotation training. Before the application process of these activities, students will receive training on the software to enable completion of the necessary introduction stage in order to construct *instrumental schema* of the participants. The tasks will be formulated according to instrumental approach and they will be given to students in a

computer laboratory. By this way, we will use SketchUp as an *instrument* for the spatial ability training process. Expected outcomes of the study are development of students' spatial visualization, spatial orientation and mental rotation skills through SketchUp's special tools, which are being designed as *instruments*.

In the study, the design of the activities has been limited with the abilities of mental rotation and spatial orientation. Within the scope of the project, the researchers have prepared activities about 3D surface developments, visualizing objects through cross-section and mental cutting (see [3]) related to visualizing objects mentally. These skills are related to geometry and mathematics success, as well as to academic performance ([12], [26], [27]). Recently, in the "Academic Staff and Graduate Education Entrance Exam," in Turkey there have been some questions regarding mental rotation and questions that measure spatial orientation skills (see [31]). Because of this, the activities designed for this study will not only help undergraduate mathematics students improve their spatial abilities but also help university students in other fields get ready for their examinations as well.

Acknowledgement

The authors would like to thank would like to thank The Scientific and Technological Research Council of Turkey (Bideb–Bayg) for their financial supports during their MSc and PhD studies. The authors are also very thankful to the referee for his/her carefully reading the paper and making constructive suggestions.

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