

Designing spatial visualization tasks for middle school students with 3D modelling software: An instrumental approach

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Abstract

In this work, certain pedagogical task designs to enhance middle school students' spatial visualization ability, in the context of an instrumental approach, have been developed. 3D modelling software, SketchUp®, was used. In the design process, software tools were focused on and, thereafter, the aim was to interpret the instrumental genesis and spatial reasoning processes of two students on the use of the software tools. In the application of the tasks, it was observed that the students were easily familiar with certain tools; however, they were not good at some and needed instrumental reinforcement. Additionally, the student whose spatial ability performance was better than the other could easily accomplish manipulation of the tools. In light of the obtained results, certain recommendations are made.

Keywords: Spatial visualization, SketchUp®, Instrumental approach, Middle school students.

1. Introduction

Imagine that you are moving to a new apartment. Can you easily place your belongings to the rooms of the apartment in your mind? While walking down a street, can you visualize your actual position in relation to the city as a whole? These questions are related to your *spatial ability* performance, defined as a combination of abilities to imagine the visualization of an object from different viewpoints, rotating it and blending or integrating parts of the given

object (McGee, 1979; Olkun, 2003; Turgut, 2007). Therefore, it is worth noting that an arbitrary person, in daily life, uses this ability, for example, while reading street *maps*, *explaining routes* to others, *slicing a pie* for a number people, *completing a puzzle* or *constructing self-assembly furniture* (Aricı & Aslan-Tutak, 2013; Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002; Wolbers & Hegarty, 2010). As a result, great attention has been given to spatial ability by Science, Technology, Engineering and Mathematics (STEM) field educators (Bosnyak & Nagy-Kondor, 2008; Németh & Hoffmann, 2006; Newcombe, 2013; Newcombe & Stieff, 2012; Peters, Chisholm, & Laeng, 1995; Sorby, 2009). In addition, to the importance of spatial ability in the engineering sciences, spatial ability is an underpinning skill in the learning 2D and 3D geometry (Turgut, 2007).

Mathematics is a core factor in all other fields, because students are exposed it from primary school to graduate level. Due to this, the National Council of Teachers of Mathematics (2000) emphasized that students' engagement in spatial activities is important for their learning of geometry. Similar suggestions have also been proposed by revised Turkish middle school and higher mathematics curricula (Turgut & Uygan, 2014). Because the main objective of mathematics curricula is to prepare people for life in their environment, they contain *spatial awareness* activities, related to the development of students' *spatial location ability* (Sarama & Clements, 2009). In conclusion, spatial ability comes to the forefront in students' entire education processes, emphasizing the importance of the integration of pedagogical *spatial ability task designs* with formal education constructed on theoretical frameworks. In this context, in this work, the aim was to develop spatial visualization tasks for middle school students with 3D modelling software, SketchUp®, within three theoretical influences, spatial thinking in mathematics education (Gutiérrez, 1996), the cognitive process of geometric reasoning (Duval, 1995, 1998), and instrumental integration (Assude, 2007). In addition, pilot studies of designs with two students were conducted, with their experiences regarding the use of the software and their reasoning processes being presented in detail.

2. Theoretical Framework

2.1. Spatial thinking and mathematics education

Spatial ability has several sub-skill definitions being used interchangeably (Cantürk-Günhan, Turgut, & Yılmaz, 2009). McGee (1979) proposes two components of spatial ability; *spatial visualization* and *spatial orientation*. Turgut and Uygan (2013) define spatial visualization as 'the ability to represent and manipulate visual objects mentally' (p. 292). This sub-skill encompasses the action of manipulating objects in the mind, *visualizing*, *rotating*, *integrating*

and *disintegrating* them, as well as mental transformations, such as *matching* and *combining* (Sarama & Clements, 2009). Spatial orientation can be defined as the ability to visualize views of given objects from different viewpoints. However, the distinction between spatial orientation and rotation is associated with the *position of the object* or *of the observer* (Xistouri & Pitta-Pantazi, 2006). Linn and Petersen (1985) categorize spatial ability into three sub-skills; *spatial perception*, *mental rotation* and *spatial visualization*. Spatial perception includes skills to comprehend relationships among figures and shapes through body orientation; mental rotation is associated with rotating figures mentally and quickly; however, spatial visualization includes multi-step manipulation of figures, such as the *closure of surfaces*, *projecting*, *translating* or *blending*.

The aforementioned skills may be included in all mathematics textbooks. Therefore, spatial ability appears as an important component of recent mathematics education research, because a strong positive relationship between spatial ability and mathematics achievement appears (Battista, 1990; Kayhan, 2005; Turgut, 2007). However, mathematics educators do not agree on the use of terminology for spatial abilities (Gutiérrez, 1996). We have such terms as *mental* or *visual image* (Presmeg, 1986), *visualization* (Yakimanskaya, 1991) and *spatial thinking* (Clements, 1998; Hauptman, 2010). In the literature, these are used interchangeably with the most common term being visualization among mathematics educators and, according to Gutiérrez (1996), this refers to a kind of ‘reasoning activity based on the use of visual or spatial elements, either mental or physical’. This is integrated into four elements, ‘*mental images*, *external representations*, the *process of visualization* and *ability to visualization*’ (p. 9). Due to the nature of mathematics, every concept might have special representation that corresponds to a mental image. At this point, a mental image is a cognitive *visual* or *spatial depiction* of a mathematical concept and it is the *basic element* for visualization (Gutiérrez, 1996). External representations are any kind of graphical pictures of concepts that assist in creating mental images, thereby opening a door onto visual reasoning. The process of visualization is associated with *mental* or *physical actions* with mental images, and it is composed of two main processes; the *visual interpretation of information* and the *interpretation of mental images* (ibid. p. 10). The first phase is to create mental images and the second is to generate information. As a result of these processes, as Gutiérrez (1996) summarizes, individuals should use one or more of the following abilities of visualization to carry out the necessary steps to create mental images and further manipulations (p. 10):

- *Figure-ground perception*: The ability to identify a specific figure by isolating it out of a complex background.
- *Perceptual constancy*: The ability to recognize that some properties of an object (real or in a mental image) are independent of size, colour, texture, or position and to remain unconfused when an object or picture is perceived in different orientations.
- *Mental rotation*: The ability to produce dynamic mental images and to visualize a configuration in movement.
- *Perception of spatial positions*: The ability to relate an object, picture, or mental image to oneself.
- *Perception of spatial relationships*: The ability to relate several objects, pictures, and/or mental images to each other, or simultaneously to oneself.
- *Visual discrimination*: The ability to compare several objects, pictures, and/or mental images to identify similarities and differences among them.

In conclusion, the spatial thinking process might include several steps of visualization and the creation of mental images. Therefore, in the case of learning 2D and 3D geometry, spatial thinking is a strong component of the process which helps someone to create additional images on the problem figure, integrate or disintegrate 3D models mentally, or to find an alternative viewpoint to solve a given mathematical task. Hypothetically, it can be stated that spatial thinking may help students to perform *geometric reasoning*. However, it is a complex process and visualization is only one part of it, as we will express in detail in the terms of Duval (1998).

2.2. Cognitive process of geometric reasoning

According to Duval (1998), students should apply three types of cognitive process while learning geometrical concepts; *visualization*, *construction* and *reasoning*. Within the visualization process, students focus on space and heuristic representations of concepts, intending to investigate different geometrical situations. Secondly, the construction process refers to operations for forming representations of geometrical concept features, which are learnt by students, considering geometrical requirements and using appropriate semiotic mediations. Thirdly, the reasoning process implies the exploration of mathematical relationships between concepts and the invariable features within them, and inferring, generalizing, proving and making explanation according to mathematical exploration. These three processes are not independent of each other, and effective applications of all of them in

the classroom support the geometrical thinking abilities of students. Moreover, according to Duval (1995), making sense of geometrical concepts is a complicated task for many students, and students apply four apprehension types while making sense of geometrical concepts; *perceptual apprehension*, *sequential apprehension*, *discursive apprehension* and *operative apprehension*. Perceptual apprehension is related to the recognition of visual properties of a geometrical concept at the first viewing of the representation of the concept. Sequential apprehension refers to whether students define a geometrical concept when they investigate construction or descriptions of the construction related to the concept. Discursive apprehension implies apprehension of properties that cannot be understood by perceptual reasoning, but which can be understood by inferring from exploration of specific geometrical properties. Operative apprehension is related to the mental or physical manipulation of a given figure with the intent of finding the solution of a problem that includes the figure (Deliyianni, Elia, Gagatsis, Monoyiou, & Panaoura, 2010).

In addition to this, Duval (1995) states that *operative skills* related to the manipulation and reconstruction of geometric figures are also critical in supporting students' *heuristic thinking* on geometric concepts and, therefore, operative skills need to be supported by manipulative tools, such as computer software, which corresponds to this theoretical view (Wu, Lai, Chang, Sung, & Hsiao, 2012). The results of many studies indicate that information and communication technologies (ICT) tools provide students with effective learning environments to develop their reasoning skills related to the visualization and manipulation of geometrical figures (Arzarello, Bairral, & Dane, 2014; Noss & Hoyles, 1996; Turgut, 2010). On the other hand, the learning process of using computer software in effective ways with the aim of supporting manipulative operation skills is emphasized as a careful designed process in the *instrumental approach* (Trouche, 2004; Vérillon & Rabardel, 1995). Moreover, according to the instrumental approach, making students utilize schemes for ICT tools depends on their teachers guiding the process and the environment (Drijvers, Doorman, Boon, Reed, & Gravemeijer, 2010). Therefore, how a teacher guides a technology-enriched environment in order to interpret students' mathematical reasoning is an important area and it has to be carefully shaped. The teacher's role in the instrumental integration process needs to be examined.

2.3. The teacher's role in the instrumental integration process

Assude, Grugeon, Laborde, and Soury-Lavergne (2006) emphasize what a teacher's role is when students' instrumental geneses, related to using an artefact, are constructed researching the issue under the title, '*instrumental integration*'. Instrumental integration describes how teachers organize facilities of an artefact provided to students for the construction of instrumental schemes and decide which components of instrumental geneses need to be supported by teachers. Instrumental integration consists of four processes; (i) instrumental initiation, (ii) instrumental exploration, (iii) instrumental reinforcement and (iv) instrumental symbiosis.

The first step of instrumental integration is the instrumental initiation where students identify the technical features of the technology and how to use its specific tools. In this first process, the teacher's purpose is to introduce the various uses of the specific tools of the technology to students, and to provide appropriate exercises for them. Interaction between technological knowledge and mathematical knowledge is at the lowest level in the instrumental initiation. The second step is instrumental exploration where teachers aim to improve students' knowledge related to both the technology and mathematics simultaneously. In this step, students explore technology within certain mathematical tasks. The extent of the interaction between technological knowledge and mathematical knowledge occurs through instructional tasks dependent on the teachers' assessments of students' instrumental geneses and instructional decisions. Thirdly, if students face obstacles when they use technology as a mediation to complete mathematical tasks, they need instruction by teachers in regard to the correct and effective use the technology within mathematical tasks, called instrumental reinforcement. In this step, teachers guide students on how to overcome obstacles, which create gaps within the instrumental usage schemes of students. Finally, the fourth step is instrumental symbiosis, through which students are able to use technology as an effective learning tool, in the same way they would use rulers, protractors or compasses to accomplish mathematical tasks. In the instrumental symbiosis step, students benefit from their technological knowledge and mathematical knowledge simultaneously, in the other words, in a symbiotic way, when they explore mathematical tasks (Assude, 2007; Assude et al., 2006).

2.4. Integration of ICT to spatial ability training and the rationale of the study

Imagine someone playing a computer game. When the game is commenced by the player, there begins a manipulation process that is twofold; a *continuing visualization* and

imagination (Turgut & Uygan, 2014). At this point, an important question arises; does this process develop spatial ability? The answer is affirmative (De Lisi & Wolford, 2002; Subrahmanyam & Greenfield, 1994). Following effective results of computer game studies, researchers designed visualization and imagination-enriched environments to improve students' spatial ability. Related studies on the effectiveness of ICT on spatial ability can be divided into three groups:

- Use of software in the training process (Kurtulus & Uygan, 2010),
- Spatial games (Hung, Hwang, Lee, & Su, 2012),
- Virtual reality applications (Hauptman, 2010).

In this respect, considering its important role in mathematics education, the development (training) of spatial ability with the aid of ICT tools has attracted great attention among mathematics educators. This is because monitoring ICT enables students to become involved in a direct and a continuous manipulation process, and to share their ideas and arguments with others. Accordingly, in the context of the development of mathematical tasks for spatial ability, geometric thinking is of crucial importance. This is because operational and cognitive manipulation of geometric shapes requires spatial thinking (Kalogirou & Gagatsis, 2011; Sarama & Clements, 2009). It has been confirmed that ICT-enriched learning environments can be effectively used not only for developing students' ability of reasoning, conjecturing and argumentation skills (Arzarello, Olivero, Paola, & Robutti, 2002), but also for developing their spatial reasoning skills (Kurtulus, 2013). In parallel to this, in this work, the aim is to enhance middle students' spatial reasoning skills by the development of certain spatial visualization tasks with SketchUp®, with reference to the theoretical considerations above, and to pilot pedagogical tasks with students in order to interpret their experiences and to describe their reasoning processes. Through this qualitative research, a connection among *spatial thinking*, *instrumental approach* and *3D modelling software* has been established.

3. Methods

3.1. The software

The software used in this study, with the intent of supporting spatial ability training is SketchUp®, a 3D modelling software first designed by the Last Software Company in 2000. After six years, Google bought out the software company, developed further versions in a number of languages, called Google SketchUp®, and provided resources, in addition to licensed provision, for all Internet users to make 3D modelling free. Lastly, in 2012, the software was bought out by Trimble and has since been continually revised. Since 2000,

SketchUp® has benefited many designers working within the engineering and architectural disciplines (Murdock, 2009). Moreover, in recent years, various studies have indicated that the software might be used effectively for geometry learning, including tessellations, figural patterns, symmetry and spatial ability activities (La Ferla et al., 2009; Turgut & Uygan, 2013, 2014). An interface view of the software includes toolbars, axes with different colours (blue, yellow, red axes are x – y – z axes, respectively), a human model as a reference to make 3D models of buildings, models of the sky, of the ground and of skylines, as well as a measurements box.

3.2. Participants

The initial participants were four (two seventh, two eighth grade) (2 boys, 2 girls) middle school students. They were informed about the aims of the research, anonymity and the training process, and thereafter, in the context of the research, two spatial ability tests were proposed; a Mental Rotations Test (version A) consisting of twelve tasks (MRT – A) (Peters, Laeng, et al., 1995) and a Card Rotation Test (CRT) (Ekstrom, French, Harman, & Dermen, 1976). The first test was associated with the mental rotation performance of figures made from unit cubes (Figure 1). The participants were tasked with finding two figures the same as the given figure on the left side. Therefore, the participants had to find two correct answers from four alternatives. There were two distractors among them. Three minutes were given to each student to accomplish the task.

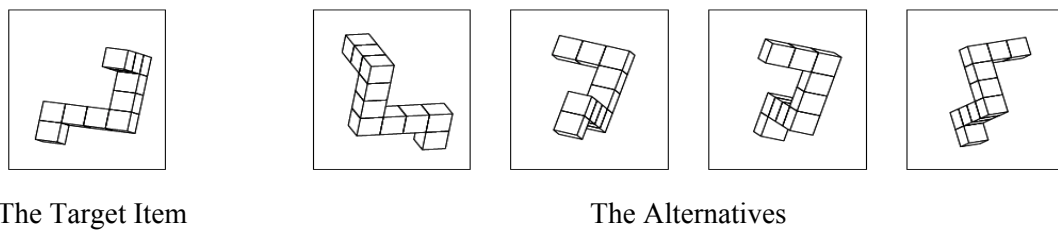


Figure 1. *A sample MRT-A task*

The second test, the CRT, was associated with rotating small figures in the mind and finding the same figures from eight alternatives. This test contained ten questions (each question had eight tasks; see Figure 2). Three minutes were given to each student to accomplish the task.

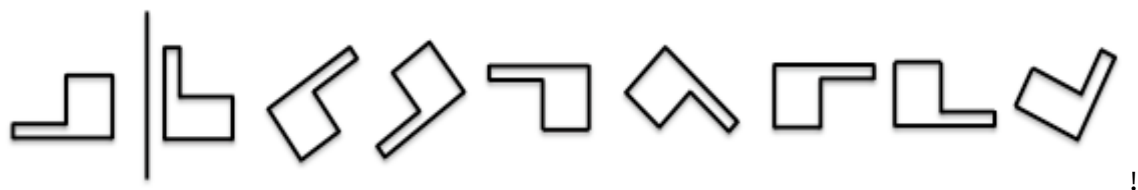


Figure 2. *A sample CRT task*

After they completed the MRT-A and CRT tests, the four students received training prepared by one of the authors. Meanwhile, the other author analysed the spatial ability test results. Finally, according to the researchers' observations and spatial ability test results (one of the boys performed better than the others), two participants (one girl, eighth grade and one boy, seventh grade) were determined. They are given the pseudonyms Birgül and Davut.

3.3. Development of the tasks and the training process

In the development process of the tasks, three theoretical influences are followed; Gutiérrez (1996) (in particular, *mental rotation, perception of spatial positions, perception of spatial relationships* and *visual discrimination* steps); Duval (1995, 1998) (*visualization, construction* and *reasoning, and operative skills* processes) and Assude (2007) (*instrumental integration*). Within this framework, inspired by sample items from a doctoral thesis (on geographical information systems) (Lee, 2005), seven tasks (two for training and five for application) have been developed for middle school students. In this context, a number of activities were developed, including rotations of given squares in a 90 degree clockwise direction, counterclockwise direction or 180 degree and, thereafter, making them overlap to obtain the target image (examples will be provide later). Within this aim, the tools of SketchUp® were determined and adapted to the environment as artifacts. These were *top view, pan, select, move, rotate, lines, eraser, rectangle, paint bucket* and *measurement box*. The tool *top view* allows for a transformation of the interface from 3D to 2D to interpret the activities. In addition, only some of the SketchUp® tools, such as orbit and push/pull, were explained, being included in the tasks in order not to spoil the 2D interface. *Pan* was shown to the students to allow them to see other sides of the interface. *Select* was necessary for students to perform several steps of the tasks. The *rotate* and *move* tools were core elements in the implementation of the tasks and were necessary to rotate the given figures on the plane and to move the objects the figure overlapped. The *lines* and *eraser* tools were used to perform the steps of drawing new lines on the rotated figures and erasing wrong or unnecessary figures and surfaces. The *rectangle* and the *paint bucket* tools enabled students to construct squares via feedback and to paint surfaces intentionally. The *measurement box* tool enabled students to examine rotational angles while they are rotating the given figure. In addition, 'colour feedback' was emphasized when the midpoint of the edges was obtained. !

In order to make students pursue the tasks, first, a *training episode* was implemented for students to accomplish the given tasks. In the *instrumental initiation* part of the design

training process, firstly, SketchUp® was outlined, with the kinds of drawings or models which can be constructed with it being explained to the students with examples. Thereafter, functions of the specific tools for SketchUp® *pan*, *zoom* and *orbit* were introduced. While the *undo* and *redo* tools were explained in detail, the *orbit* and *zoom* tools were omitted because the students would not have been able to use them in the application. Thereafter, the *lines* and *rectangle* tools and their functions were introduced, and how the *colour feedback*, *square feedback* and *measurement box* tools are used was explained. In order to look at things from different views, the *views* window was also introduced. In this sense, the students were allowed to make sample drawings and, within this process, the researchers intervened when there were failings on the use of the tools or incorrect drawings were made (Figure 3). !



Figure 3. *Researchers' intervention through training*

As a next step, the *select*, *move* and *rotate* tools, which were very important in performing the given tasks, were introduced with several examples, and possible mistakes which could occur were pointed out. Four possible mistakes were proposed to the students: (i) not selecting the whole figure to be rotated or moved; (ii) selecting the wrong points to move the figures; (iii) deficiencies in finding the centroid of the figures; and (iv) not controlling the measurement of angles from the measurement box. For the instrumental exploration part, two of the activities were given to students to enable them to practise the use of the tools accurately and quickly. The SketchUp® interface regarding this process is expressed in Figure 4.

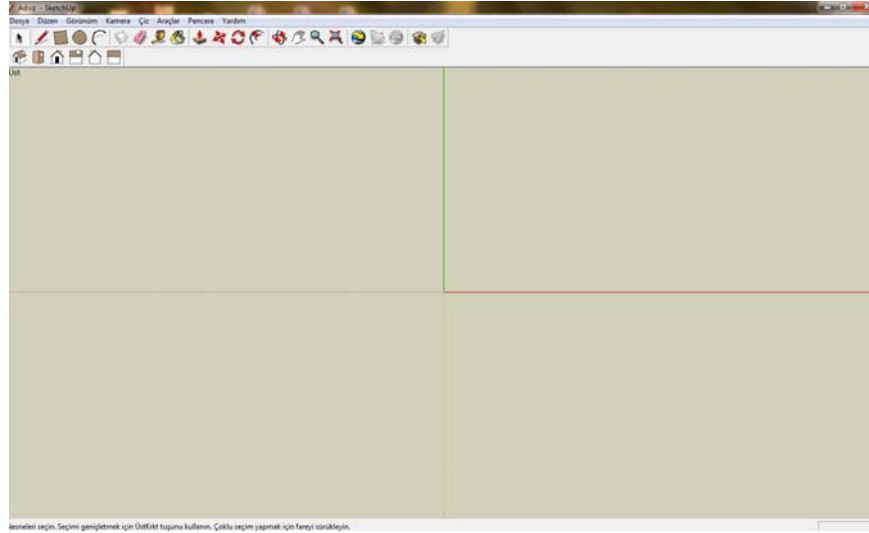


Figure 4. *SketchUp® interface as proposed to the students*

In the instrumental exploration process, it was thought that deficiencies and mistakes could be detected while the students were using the *select*, *rotate* and *move* tools. The tasks in this step are related with how two squares should be rotated and moved one on top of the other. In these questions, the students found solutions comparing the given figures and thereafter, they evaluated their solutions in terms of the software's tools. A sample task is given in Figure 5.

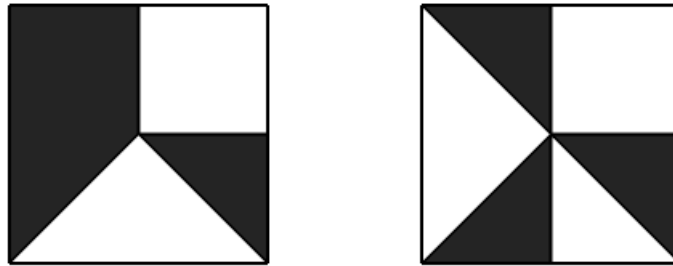


Figure 5. *Sample task for instrumental exploration part*

The figure on the right is rotated clockwise 180 degrees, and the figure on the left is rotated 90 degrees clockwise. Thereafter, one of figures is moved (superposed) onto the other. Find the final image.

In the third question, the students were requested to find the final image rotating the given two squares within certain angles and directions, and then moving one onto the other. Figures in this question were not as easy as in the previous question, and the researchers expected that the students would need to use the software's tools more often. For this question, it was thought that students would first draw the solutions that they visualized in their minds on paper. It was then expected that the students would make dynamic images via the tools and

make reasoning while solving the task. It was thought that the students would complete the task using a trial-and-error strategy.

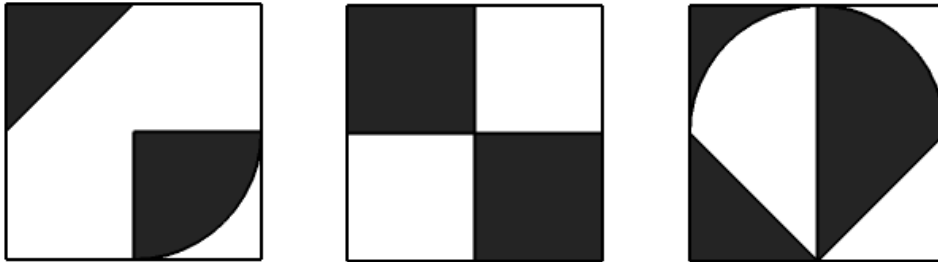


Figure 6. *The squares used in the fourth task*

Two of the squares in the figure above are separately rotated within certain angles and directions and the three figures are moved onto each other. Finally, the following figure is obtained.



Figure 7. *The final image in the fourth task*

In which directions should these figures be rotated and at what angles?

In the fourth task, students were asked to obtain Figure 7. They were asked which two of the figures (Figure 6) should be rotated in which directions and at what angles to achieve the result also using the third figure. It was expected that the students would use the software's tools accurately and quickly. Moreover, it was also expected that they would use the *measurement box* tool several times, using *undo* in the trial-and-error process.

In the fifth question, the students were requested to form (draw and move) figures in certain directions and angles to achieve the given final image (Figure 8). This question was open-ended as a fourth question and had multiple solutions to foster the students' reasoning steps. Besides this, it was expected that the students would use the *lines*, *rectangle*, and *erase* tools

and would underpin spatial reasoning via the *rotate* tool. The fifth task is presented in Figure 8.

One of the three figures is rotated 180 degrees in a clockwise direction, the second is rotated 90 degrees in a clockwise direction and the last is rotated 90 degrees in an anticlockwise direction. They are then moved onto each other. Finally, the following figure is obtained:



Figure 8. *The final image of the fifth task*

Form these figures in SketchUp®.

3.4. Analysis of the data

In order to analyze the obtained data, six steps as described in Braun and Clarke (2006) were followed; (i) familiarization with data, (ii) generation of initial codes, (iii) search for themes, (iv) review of themes, (v) defining and naming themes, and (vi) producing the report.

4. Results

4.1. Birgül's initial instrumental genesis process regarding the software

1. It was observed that Birgül was able to determine the midpoints of edges and diagonal lines in quadrangles as well as the centroid of quadrangles with the help of the *colour feedback* tool during the activities, using this tool very effectively.
2. It was seen that she used the *drawing* tool easily while dividing the square surface into equally sized parts and drawing diagonal lines in a square.
3. It was observed that Birgül continuously examined the changing values of angles given in the measurement control box, so as to finish the rotation accurately according to the given rotational angles.
4. It was observed that Birgül initially preferred to rotate by pressing and holding the left click button of the mouse on random points on the quadrangles, but later rotated them using the corner points of these quadrangles.

4.2 The instrumental reinforcement Birgül needs

1. While using the *rotate* tool, Birgül started without selecting the entire image. At this point, the researcher reminded her how to do it. It is clear that Birgül quickly realized her mistake after support was given.
2. While moving the images, Birgül tried to move the image onto another one by pressing and holding the left click button of the mouse on a random point of the image. However, she did not manage to move the image to the place she wanted. At this point, the researchers pointed out that moving would be easier if it was done by pressing and holding the left click button of the mouse on certain special points (corners). Birgül did the moving correctly after a short time accordingly.
3. While painting a square surface, Birgül received support from the researchers in regard to distinguishing the surfaces from each other and making this selection separately. She managed to do it by herself after a short time.
4. Birgül especially asked for help in deleting the triangular areas she formed. The researchers showed her how to do it by using the right click button of the mouse. However, it took some time for Birgül to make the deletion herself. She made mistakes while selecting the images and deleted ones she did not want to by mistake. At this phase, the researchers emphasized the importance of making correct selections. *Deleting* is a task for which Birgül needed instrumental reinforcement.
5. It was observed that initially Birgül did not know how to correct mistakes she had made. At this point, the researchers showed Birgül how to use the *undo* tool.

4.3 Birgül's instrumental utilization scheme

The utilization scheme for the activities realized by Birgül for the first four tasks, as part of the 2D spatial visualization studies, involved the following steps:

Selecting the entire image - determine its midpoint using the *colour feedback* tool and mark it as the rotation point - press and hold the left click of the mouse on any point of the square or its corners in order to rotate the image - get feedback from the measurement control box and rotate the image - select the *move* tool and move the shape by clicking and holding on the corner point – superpose this corner point of the image with the corresponding corner of the other.

The scheme for the fifth task is as follows:

Find the midpoints with the help of the *colour feedback* tool - divide the image into pieces, drawing lines passing through the midpoints and diagonal lines - select the redundant parts

and delete them - select those suitable and paint them using the *paint box* tool - delete certain surfaces to make them transparent - rotate those completed by following the process and move them onto each other, evaluating the result.

4.4 Birgül's spatial reasoning during the process

Birgül arrived at a decision in the first two tasks by rotating the images in her mind first. Later, she decided which image she would take as a reference while working with the software (generally the image on the left). It was observed that she had difficulty in carrying out the rotation tasks, requiring an anticlockwise rotation whilst working on clockwise ones, in her mind. It was seen that she received help while conducting anticlockwise rotations using certain special tools. Birgül stated, at the end of the process, "You can, at least, try while using the software. It is difficult here (the working sheet). It is easier to visualize here (software)". It was observed that Birgül always focused on the manipulation of the images on the left for the open-ended questions. She found it difficult when she had to start with the images on the right. At this phase, it was observed that she re-examined the image by moving it to the left of the other shapes and achieved the task objectives very quickly.

A sample process is described in the notes of researchers as follows: "When Birgül compares the image she formed (the one on the left) with the one in the centre, she is not able to figure out how to rotate the one in the centre (it is necessary to rotate the shape clockwise or 90° anticlockwise). Birgül gives up on the last task and moves the image on the right onto the one in the centre by pressing and holding it on the corner points."

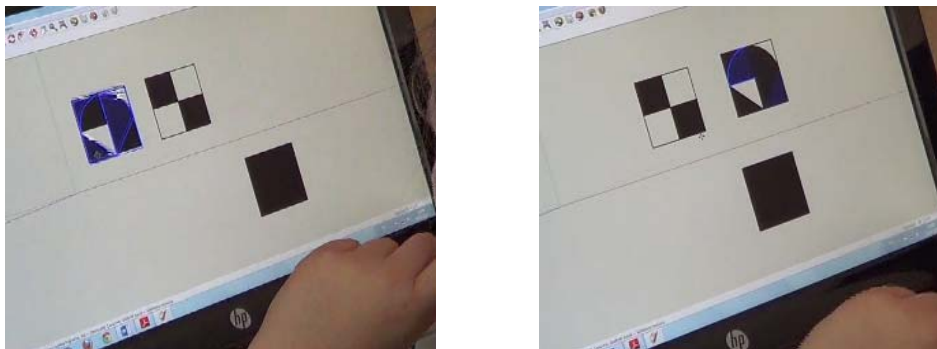


Figure 9. Birgül's reasoning steps for the fourth task

The fifth task states that the image at the bottom is formed by rotating three images and superposing them all together; one of the images is rotated 90° clockwise, the other 90° anticlockwise and the third one 180° .

It was observed that Birgöl divided the blank square templates into four pieces very quickly and started to think about them when she started the fifth task. Later, she did not make instant decisions regarding the next image to be formed or their positions. She tried to form the required images through a trial and error technique and followed a spatial-analytical strategy.

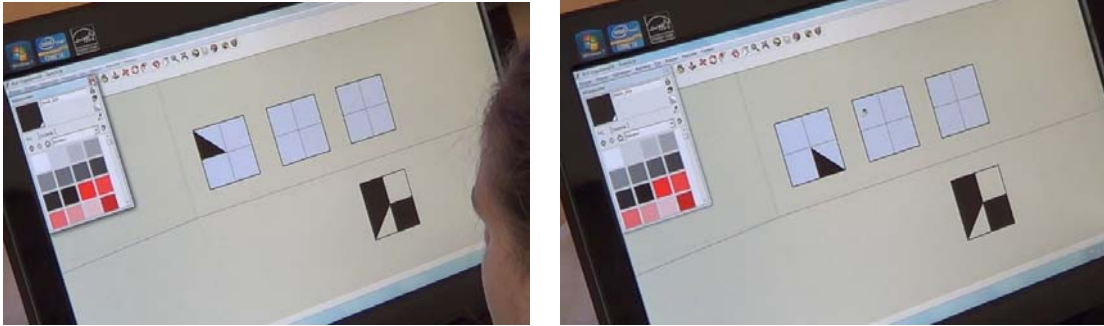


Figure 10. *Spatial-analytical strategy of Birgöl in the fifth task*

While Birgöl was examining the images required to be formed in the tasks, she divided the image at the bottom simply into three pieces in her mind (two equal squares and one right triangle) and thought about the shapes of these pieces. On the other hand, Birgöl examined the possible shapes of the images rotated anticlockwise, and superposed these images by rotating them, keeping the image to be rotated anticlockwise to a later time. In addition, she was observed to regularly apply the following tools while forming the outcome image: *rotating*; *deleting*; *redrawing*; and *clock / anticlockwise rotation*.

In this process, the software is thought to support Birgöl by providing a dynamic visualization of moving images and a user-friendly application of rotation tasks.

4.5 Davut's initial instrumental genesis process regarding the software

1. It was observed that Davut was easily able to determine the midpoints of edges and diagonal lines in quadrangles as well as the midpoints of quadrangles with the help of the *colour feedback* tool during the activities.
2. Davut was observed to use the *quadrangle* tool as well as the *drawing* tool while dividing the square area into equal parts. In addition, he formed small squares $\frac{1}{4}$ of the overall square area with the help of the *square feedback* tool.
3. It was observed that Davut used 15^0 parts as measured by the protractor while conducting the rotation accurately depending on the angle given for the particular task.

4. It was observed that Davut used the *undo* tool often and very quickly while working on the images.
5. David was observed to move the image by pressing and holding the left click button of the mouse on the midpoint and superpose it with the midpoint of the other image.
6. It was observed that Davut rotated the quadrangles by pressing and holding the left click button of the mouse on the midpoints of their edges.
7. Davut was observed to use the *paint bucket* tool correctly to paint the polygonal areas he had formed using the software.

4.6 Instrumental reinforcement Davut's needs

1. Before Davut used the rotation function for the first time, he asked which axis he could use for the rotation. At this point, the researchers told him that the blue protractor icon should be clicked, since it works on a surface formed by the red and the green axis.
2. Since Davut was not able to select the entire image during the rotation of the quadrangle, the result was a deformation in its shape. At this point, the researchers reminded Davut that the entire image should be selected first.
3. Davut asked for help while deleting certain parts of the image he had formed. The researchers told that the *delete* option should be clicked after the part to be deleted is selected by a right click button of the mouse. Davut quickly learned how to use this method.
4. Davut received a little help from the researchers while deleting redundant surfaces. After this support, Davut was able to apply the deleting function quickly and effectively.

4.7 Davut's instrumental utilization scheme

The utilization scheme for the activities realized by Davut for the first four tasks, as part of the 2D spatial visualization studies, involved the following:

Select the entire image - determine the midpoint of the image with the help of the *color feedback* tool and mark this point as the rotation point - press and hold the left click button of the mouse on the midpoint of the square in order to rotate the image - rotate the image using 15⁰ parts on the protractor sign at the given angles - select the entire image to be moved - select the *move* tool and move the image by pressing and holding the left click button of the

mouse on the midpoint or corner point - superimpose the clicked and held point of the image with the corresponding point of the other image.

The utilization scheme for the fifth task follows this order:

Find the mid-points of the corresponding edges in the square template - draw a line connecting the midpoints of two corresponding edges - draw a square having a $\frac{1}{4}$ size of the square template with the help of *quadrangle* tool and the *square feedback* available in this tool - select the pieces thought to be redundant and delete them - draw a diagonal line for the $\frac{1}{4}$ unit size square and delete half to make a right angle triangle - select the necessary areas and paint them using the *paint bucket* tool - delete certain pieces to make them transparent - superimpose the formed pieces by the process mentioned above and evaluate the outcome.

4.8 Davut's spatial reasoning during the process

Davut always focused on the manipulation of the image on the left while starting reasoning on the images. He stated that it was easier to start the process this way. Davut thought about the rotated versions of the images separately and drew them on a piece of paper accordingly. However, the researchers observed that Davut did not draw certain parts and realized his mistake while examining the moving images in the software. In addition, Davut was observed to draw the rotated versions of the images on paper by rotating the paper accordingly. At this point, it was thought that Davut avoided imagining the rotation in his mind.

It was observed that Davut rarely examined the measurement control box. In addition, he rotated the images quickly and accurately and followed a spatial holistic strategy. In other words, he took the protractor icon rather than the measurement control box as a reference. As for the solution to task four, Davut did not have difficulty in the anticlockwise rotation and superimposing the images. In addition, he was observed to initially focus on the 180° rotation and later the 90° anticlockwise rotation tasks whilst examining the rotations for this open-ended question.

While examining the solution to task five, Davut was seen to simply divide the image given into 3 pieces, divide the square templates into two equal pieces through lines and draw squares inside these templates as a $\frac{1}{4}$ scale of the original. Davut drew the pieces of the image given into blank templates in such a way that they would be in the same position, and completed the task accordingly. In other words, he integrated deductive reasoning into the spatial reasoning process at this phase.

Across this study's results, Table 1 summarizes the instrumental utilization schemes of Birgül and Davut in the context of the proposed spatial visualization tasks.

Table 1. *Students' instrumental utilization schemes*

	Students' First Instrumental Genesis	Instrumental Reinforcement by Teachers	Support of the software in reasoning process
Birgül	Using colour feedback accurately *	<ul style="list-style-type: none"> • Selecting the image prior to rotation** • Selecting special points on the image during rotation • Selecting surfaces prior to painting • Selecting the target part prior to deletion** • The use of the undo tool 	Dynamic visualization on the images required to be rotated
	Using drawing tool accurately*		The support for the visualization of anticlockwise rotation
	Following the angle value in the measurement control box		The support for the visualization of angle values***
	Using corner points of figures in rotation tasks		The support for the evaluation of the drawings made on paper***
			The support in exchanging the positions of 2D shapes (right-left)
Davut	Using colour feedback accurately*		
	Using the square tool while using the quadrangle tool		Dynamic visualization on the images required to be rotated***
	Using drawing tool accurately*	<ul style="list-style-type: none"> • Determining the axis to be used for rotation 	The support for the visualization of angle values***
	Using angle values in protractor icon during rotation	<ul style="list-style-type: none"> • Selecting the image prior to rotation** 	The support for the evaluation of the drawings made on paper***
	Using undo tool	<ul style="list-style-type: none"> • Selecting the target part prior to deletion** 	
	Using move tool accurately		
	Using the midpoints of edges during rotation		
Using the paint bucket tool accurately			

*, ** and *** indicate common schemes in each columns.

5. Discussion and Implications

In this work, the first aim was to develop spatial visualization tasks in the context of an instrumental approach. The second aim was to investigate middle students' experiences and their spatial reasoning processes while they were solving the proposed tasks. The results

reveal that the students were able to apprehend the software’s artefacts and their usage and they were able to use those artefacts in solving the tasks quickly. Although the researchers considered when the students would need instrumental reinforcement before the application of the tasks, the students had more deficiencies on the use of the *undo* and *erase* tools. However, through the researchers’ reinforcement, the students accomplished the use of the desired tools. The students focused on certain specific tools of the software while they were implementing the tasks and during the reasoning process. In addition to this, they used some tools as *complementary*. These tools are summarized in Table 2.

Table 2. *Students’ reasoning tools associated with solving the spatial tasks*

Key Tools for Reasoning	Complementary Tools
Measurement Box	Drawing tool
Rotate	Delete
Move	Paint
Protractor Sign	

The students were able to follow different steps while they were creating dynamic visual images. These steps are presented in Figure 11. Figure 11 shows that while Davut implemented certain operations that needed to be manipulated in his mind (e.g. comparing the figures in different positions), Birgül was able to perform the next step after she completed the interim steps (e.g. reasoning on an anti-clockwise rotation). We believe that these differences are due to their different spatial ability performances that were measured before the training and application. As a result of this, we observed that the student with higher spatial ability managed to implement his instrumental genesis with regard to use of SketchUp® quickly.

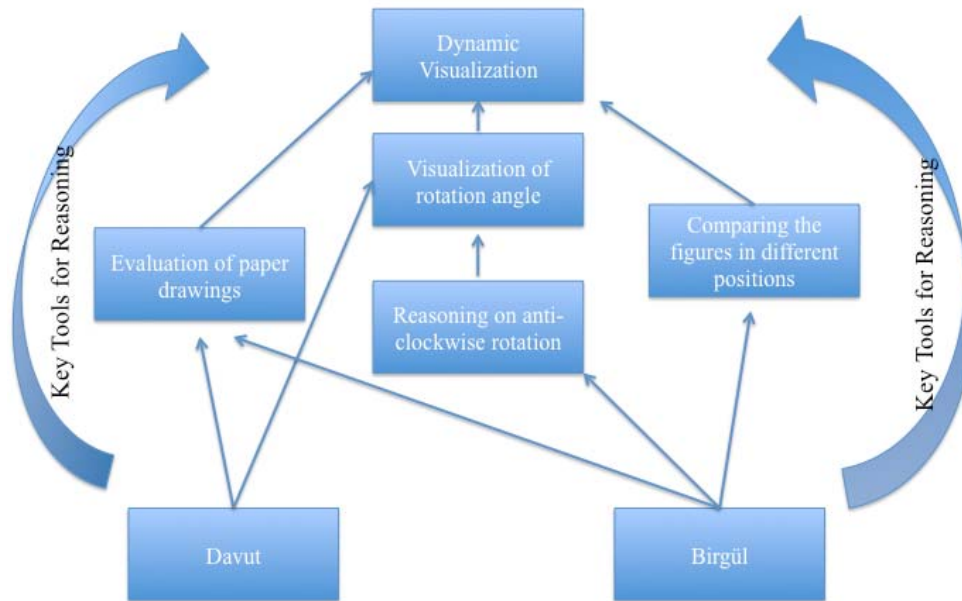


Figure 11. *Students' spatial reasoning processes while solving the tasks*

Experimental-quantitative studies conducted in the literature show that spatial ability can be trained with 3D manipulation (Kurtulus & Uygan, 2010; La Ferla et al., 2009). However, in this qualitative study, we highlight the students' experiences and psychological processes with respect to use of SketchUp®. Moreover, we describe how learning environments should be designed to interpret students' thinking processes and which steps should be carefully prepared in detail. In addition, we observe that to contribute to middle school students' mental rotation skills, SketchUp® can be used within similar carefully designed tasks. One limitation of this work is that we only focused on students' 2D mental rotation skills. For follow up studies, we suggest that pedagogical designs for middle school students using SketchUp® 3D tools, *orbit*, *push-pull* and *suchlike*, may be effectively developed by researchers.

References

- Arici, S., & Aslan-Tutak, F. (2013). The effect of Origami-based instruction on spatial visualization, geometry achievement, and geometric reasoning. *International Journal of Science and Mathematics Education*, 1-22. doi: 10.1007/s10763-013-9487-8
- Arzarello, F., Bairral, M., & Dane, C. (2014). Moving from dragging to touchscreen: geometrical learning with geometric dynamic software. *Teaching Mathematics and Its Applications*, 33, 39-51.
- Arzarello, F., Olivero, F., Paola, D., & Robutti, O. (2002). A cognitive analysis of dragging practises in Cabri environments. *Zentralblatt für Didaktik der Mathematik*, 34(3), 66-72.
- Assude, T. (2007). Teacher's practices and degree of ICT integration. In D. Pitta-Pantazi & G. Philippou (Eds.), *Proceedings of the Fifth Congress of the European Society for Research in Mathematics Education* (pp. 1339-1348). Lyon, France.
- Assude, T., Grugeon, B., Laborde, C., & Soury-Lavergne, S. (2006). Study of a teacher professional problem: how to take into account the instrumental dimension when using Cabri-geometry? In

- C. Hoyles, J. B. Lagrange, L. H. Son, & N. Sinclair (Eds.), *Proceedings of the Seventeenth ICMI Study Conference "Technology Revisited"*. Hanoi: Hanoi University of Technology.
- Battista, M. T. (1990). Spatial visualization and gender differences in high-school geometry. *Journal for Research in Mathematics Education*, 21(1), 47-60. doi: Doi 10.2307/749456
- Bosnyak, A., & Nagy-Kondor, R. (2008). The spatial ability and spatial geometrical knowledge of university students majored in mathematics. *Acta Didactica Universitatis Comenianae Mathematics*, 8, 1-25.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3, 77-101.
- Cantürk-Günhan, B., Turgut, M., & Yılmaz, S. (2009). Spatial Ability of a Mathematics Teacher: The Case of Oya. *IBSU Scientific Journal*, 3(1), 151-158.
- Clements, D. H. (1998). *Geometric and spatial thinking in young children*
- De Lisia, R., & Wolford, J. L. (2002). Improving Children's Mental Rotation Accuracy With Computer Game Playing. *The Journal of Genetic Psychology: Research and Theory on Human Development*, 163(3), 272-282.
- Deliyianni, E., Elia, I., Gagatsis, A., Monoyiou, A., & Panaoura, A. (2010). A theoretical model of students geometrical figure understanding. In V. Durand-Guerrier, S. Soury-Lavergne, & F. Arzarello (Eds.), *Proceedings of the 6th Congress of the European Society for Research in Mathematics Education* (pp. 696-705). Lyon, France.
- Drijvers, P., Doorman, M., Boon, P., Reed, H., & Gravemeijer, K. (2010). The teacher and the tool: instrumental orchestrations in the technology-rich mathematics classroom. *Educational Studies in Mathematics*, 75, 213-234.
- Duval, R. (1995). Geometrical pictures: Kinds of representation and specific processings. In R. Sutherland & J. Mason (Eds.), *Exploiting mental imagery with computers in mathematics education* (pp. 142-157). Berlin: Springer.
- Duval, R. (1998). Geometry from a cognitive point of view. In C. Mammana & V. Villani (Eds.), *Perspectives on the teaching of geometry for the 21st century: An ICMI study* (pp. 37-52). Dordrecht: Kluwer.
- Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Manual for Kit of Factor-Referenced Cognitive Tests*. Princeton, NJ: Educational Testing Service.
- Gutiérrez, A. (1996). Visualization in 3-dimensional geometry: In search of a framework. In L. Puig & A. Gutiérrez (Eds.), *Proceedings of the 20th Conference of the International Group for the Psychology of Mathematics Education* (pp. 3-19). Valencia: Universidad de Valencia.
- Hauptman, H. (2010). Enhancement of spatial thinking with Virtual Spaces 1.0. *Computers & Education*, 54(1), 123-135. doi: Doi 10.1016/J.Compedu.2009.07.013
- Hegarty, M., Richardson, A. E., Montello, D. R., Lovelace, K., & Subbiah, I. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence*, 30, 425-447.
- Hung, P. H., Hwang, G. J., Lee, Y. H., & Su, I. H. (2012). A cognitive component analysis approach for developing game-based spatial learning tools. *Computers & Education*, 59, 762-773.
- Kalogirou, P., & Gagatsis, A. (2011). A first insight of the relationship between students' spatial ability and geometrical figure apprehension. *Acta Didactica Universitatis Comenianae Mathematics*, 11, 27-39.
- Kayhan, E. B. (2005). *Investigation of high school students' spatial ability*. (Master of Science Dissertation), Middle East Technical University, Ankara, Turkey.
- Kurtulus, A. (2013). The effects of web-based interactive virtual tours on the development of prospective mathematics teachers' spatial skills. *Computers & Education*, 63, 141-150. doi: Doi 10.1016/J.Compedu.2012.11.009
- Kurtulus, A., & Uygan, C. (2010). The effects of Google Sketchup based geometry activities and projects on spatial visualization ability of student mathematics teachers. *Procedia Social and Behavioral Sciences*, 9, 384-389.
- La Ferla, V., Olkun, S., Akkurt, Z., Alibeyoglu, M. C., Gonulates, F. O., & Accascina, G. (2009). An international comparison of the effect of using computer manipulatives on middle grades students' understanding of three-dimensional buildings. In: , (Eds). (pp. 1-5), 6 - 9 July 2009, . In C. Bardini, D. Vagost, & A. Oldknow (Eds.), *Proceedings of the 9th International Conference on Technology in Mathematics Teaching – ICTMT9*. France: University of Metz.

- Lee, J. W. (2005). *Effect of GIS learning on spatial ability*. (Doctoral Dissertation), Texas A&M University, Texas.
- Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development*, 1479-1498.
- McGee, M. G. (1979). Human spatial abilities: psychometric studies and environmental, genetic, hormonal, and neurological influences. *Psychological bulletin*, 86(5), 889-918.
- Murdock, K. L. (2009). *Google SketchUp and SketchUp Pro 7 Bible*. Indianapolis, USA: Wiley Publishing Inc.
- National Council of Teachers of Mathematics. (2000). *Principles and Standards for School Mathematics*. Virginia: NCTM.
- Németh, B., & Hoffmann, M. (2006). Gender differences in spatial visualization among engineering students. *Annales Mathematicae et Informaticae*, 33, 169-174.
- Newcombe, N. S. (2013). Seeing relationships: using spatial thinking to teach science, mathematics, and social sciences. *American Educator*, 37(1), 26-31.
- Newcombe, N. S., & Stieff, M. (2012). Six Myths About Spatial Thinking. *International Journal of Science Education*, 34(6), 955-971. doi: Doi 10.1080/09500693.2011.588728
- Noss, R., & Hoyles, C. (1996). *Windows on Mathematical Meanings: Learning Cultures and Computers*. Dordrecht: Kluwer.
- Olkun, S. (2003). Making connections: Improving spatial abilities with engineering drawing activities. *International Journal of Mathematics Teaching and Learning*, 3(1), 1-10.
- Peters, M., Chisholm, P., & Laeng, B. (1995). Spatial ability, student gender, and academic performance. *Journal of Engineering Education*, 84, 69-73.
- Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn Vandenberg and Kuse mental rotation test: Different versions and factors that affect performance. *Brain and Cognition*, 28, 39-58.
- Presmeg, N. C. (1986). Visualization in high school mathematics. *For the Learning of Mathematics*, 6(3), 42-46.
- Sarama, J., & Clements, D. H. (2009). *Early Childhood Mathematics Education Research: Learning Trajectories for Young Children*. New York: Routledge.
- Sorby, S. A. (2009). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education*, 31(3), 459-480.
- Subrahmanyam, K., & Greenfield, P. M. (1994). Effect of video game practice on spatial skills in girls and boys. *Journal of Applied Developmental Psychology*, 15(1), 13-32.
- Trouche, L. (2004). Managing the complexity of human/machine interactions in computerized learning environments: Guiding students' command process through instrumental orchestrations. *International Journal of Computers for Mathematical Learning*, 9(3), 281-307.
- Turgut, M. (2007). *İlköğretim II. kademedeki öğrencilerin uzamsal yeteneklerinin incelenmesi*. (M.Sc. Master of Science Dissertation), Dokuz Eylül University, Institute of Educational Sciences, Izmir, Turkey.
- Turgut, M. (2010). *Teknoloji destekli lineer cebir öğretiminin ilköğretim matematik öğretmen adaylarının uzamsal yeteneklerine etkisi*. (Doctoral Dissertation), Dokuz Eylül University, Institute of Educational Sciences, Izmir, Turkey.
- Turgut, M., & Uygan, C. (2013). Spatial ability training with a 3D modelling software. In E. Fagigiano & A. Montone (Eds.), *Proceedings of the 11th International Conference on Technology in Mathematics Teaching* (pp. 292-297). Bari, Italy: University of Bari Aldo Moro.
- Turgut, M., & Uygan, C. (2014). Spatial ability training for undergraduate mathematics education students: Designing tasks with SketchUp. *The Electronic Journal of Mathematics and Technology*, 8(1), 53-65.
- Vérillon, P., & Rabardel, P. (1995). Cognition and artifacts. A contribution to the study of thought in relation to instrumented activity. *European Journal of Psychology of Education*, 10(1), 77-101.
- Wolbers, T., & Hegarty, M. (2010). What determines our navigational abilities? *Trends in Cognitive Sciences*, 14(3), 138-146. doi: Doi 10.1016/J.Tics.2010.01.001

- Wu, L. J., Lai, S. C., Chang, K. E., Sung, Y. T., & Hsiao, H. S. (2012). The effect of learning spatial geometry by mobile devices In G. Biswas, L. H. Wong, T. Hirashima, & W. Chen (Eds.), *Proceedings of the 20th International Conference on Computers in Education ICCE 2012* (pp. 354-361). Singapore National Institute of Education, Nanyang Technological University.
- Xistouri, X., & Pitta-Pantazi, D. (2006). Spatial rotation and perspective taking abilities in relation to performance in reflective symmetry tasks. In J. Novotna, H. Moraova, M. Kratka, & N. Stehlikova (Eds.), *30th Conference of the International Group for the Psychology of Mathematics Education* (Vol. 5, pp. 425-432). Prague: PME.
- Yakimanskaya, I. S. (1991). *The development of spatial thinking in schoolchildren* (Vol. 3). Reston, USA: NCTM.