Examining the Spatial Abilities of 6th Grade Students in a Computer-Based Instruction

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Abstract

Spatial ability is frequently encountered in professional disciplines and daily life. In general, it includes abilities such as rotating objects, estimating the appearance of objects based on a person's position, and being able to think of open and closed forms of three-dimensional objects. It is essential in learning and teaching geometry. In this research, we tried to examine the spatial abilities of 6th grade students through Visualize-Predict-Check (VPC) heuristic in a computer-based environment (GeoGebra). In the research, we designed the teaching materials according to the topics such as reflection, translation, rotation, view from different directions, and expansion, which are included in the mathematics curriculum. The experimental method was used in the research, and the Spatial Reasoning Instrument (SRI) was used for pre-test and post-test. The research groups were 75 students selected from 223 6th grade students studying in four public secondary schools in a large province of the Black Sea Region during the 2022-2023 academic year. These students were selected according to their pre-test scores and were divided into three heterogeneous groups of 25 students each. The result of the research indicates that through the VPC heuristic, there was no statistically significant difference between the scores of the first group of students in the spatial reasoning instrument when teaching was carried out only according to the visualization component. However, there was a statistically significant difference between the scores of the second and third group students in the spatial reasoning instrument when teaching was carried out, respectively, according to the visualization-prediction and visualization-prediction-control components. Based on the findings, suggestions were made for further research.

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Key words. *Spatial ability, Spatial Reasoning Instrument (SRI), Visualize-Predict-Check (VPC) heuristic, Computer-based instruction, GeoGebra.*

Introduction

Spatial ability is a crucial component in spatial thinking and generally includes abilities such as rotating objects, estimating the appearance of objects based on a person's position, and being able to think of open and closed forms of three-dimensional objects. Spatial thinking, broadly defined as the ability to generate, manipulate, and reason about spatial relationships between and within objects, is widely recognized as an essential contributor to mathematics performance (Hawes et al., 2022). Spatial ability is also frequently encountered in professional disciplines and daily life (Buckley et al., 2018). Therefore, it is essential in learning and teaching geometry (Gilligan, 2017; Hannafin, 2008; Kösa, 2016). Different classifications are made regarding the dimensional components of spatial ability. It can be stated that it is divided into dimensions such as *spatial relations, spatial visualization, spatial orientation, mental rotation,* and *spatial perception* (Clements & Battista, 1992; Contero et al., 2005; Linn & Petersen, 1985; Lohman, 1979; Maier 1996; McGee, 1979). *Spatial relationship* is the comprehension of the order of objects within a visual stimulus pattern (McGee, 1979) to and it includes understanding the spatial configuration or components of objects and their relations to each other (Maier, 1996), *spatial visualization* is the visualization and manipulation of complex spatial information for a figure/object after moving or displacing its components, so it includes mentally opening, rotating, or bending a figure/object inside out (Linn & Petersen, 1985; Maier, 1996), *spatial orientation* is expressed as understanding the relationships between the positions of objects in space according to one's position (Clements & Battista, 1992), *mental rotation* is rotation of two- and three-dimensional objects in the mind accurately and quickly (Linn & Petersen, 1985), and *spatial perception* is the designation of spatial relationships about the horizontal or the vertical locations despite of distracting information (Maier, 1996). However, it can be said that there is no general consensus on both definitions of spatial ability and its components.

National exam results and international student evaluation reports such as PISA and TIMMS demonstrate that the desired success is not achieved regarding students' geometric problem solving and spatial thinking skills (MEB, 2019; OECD, 2019). Since it is thought that basic mathematical skills such as problem solving, association, and reasoning cannot be developed with traditional mathematics learning and teaching approaches, our mathematics learning and teaching practices need to be redefined and reviewed in line with the demands of the modern age. Rapidly changing and developing technology continues to affect the current understanding of education significantly. It is thought that using and integrating technology in mathematics education is essential to increase students' conceptual comprehension, cognitive skills, questioning, and interpretation skills (Doğan, 2013). Developments in computer technologies offer many new opportunities to increase students' comprehension levels in the learning-teaching process. Especially in mathematics and geometry courses where abstract concepts and relations are discussed, computer-based mathematics teaching has gained importance in concretizing these concepts and relations. Baki (2002) states that computer-based mathematics education enables students to discover their deficiencies and performance through mutual interaction, to take control of their learning with feedback, and to increase their interest in the course with the help of graphics, animations, and shapes.

Using technology in mathematics supports the relationship between mathematical knowledge and practice, allowing students to try, visualize, and test new understandings. Thus, instead of routine algorithms and pen-paper techniques, learning and teaching environments can be designed by building mathematical models and focusing on relationships (Olive et al., 2009). Technological environments provide convenience in developing geometry-related activities (Laborde et al., 2006). Dynamic geometry software saves geometry from the paper-pencil process, which causes it to be static. It makes it dynamic on the computer screen, allowing students to make assumptions, discover theorems and relationships, and check them (Baki et al., 2004).

When the researches conducted to increase geometry success and spatial thinking skills are examined, it is generally argued that training on three-dimensional objects (such as with dynamic geometry software and using concrete manipulatives) may have an effect. In these researches, the relationships between the spatial abilities of participants at different academic levels and their general grade point averages, geometry achievements, and whether they are affected by factors such as gender or preschool education were examined. (e.g. Baki et al., 2011; Dündar et al. 2019; Güven & Kosa, 2008; Ha ve Fang, 2017; Şimşek & Yücekaya, 2014). It is also noteworthy that the researches conducted are generally conducted with teacher candidates or the effect of computer-based environments on spatial abilities or attitudes to technology or geometry. On the other hand, it is seen that researchers use traditional methods such as paper folding and cutting and technological environments. For example, Arıcı and Aslan-Tutak (2015) observed the effect of the origami-based course on tenth grade students' spatial abilities and geometric reasoning, and Patahuddin et al. (2020) stated that the VPC heuristic enabled students to participate in spatial visualizations with the instructions given, and significantly increased the students' spatial abilities in the routine. However, Xie et al. (2020) indicates in their research on meta-analysis of the relationship between the mathematical and spatial ability that the relationship is controversial and not simply linear.

In this research, we tried to examine the effect of the VPC heuristic on the development of students' spatial abilities. The visualize, predict, and check components specified in the VPC heuristic are used implicitly in various ways in mathematics education. The *visualize* component is a fundamental element of problem solving and reasoning (Arcavi, 2003). It results from interpreting and projecting real-life images mentally, on paper or through technology. Visualization is a complex process of structuring, representing and transforming mental images. It is a product, process, and ability to reflect, use, interpret and create images, pictures, and diagrams in our minds, on paper or with technological tools in order to describe and establish relations between previously unknown ideas and information about further understandings (Bishop, 2003; Yılmaz, 2011; Zimmermann & Cunningham, 1991). In the *predict* component, it has been stated that making predictions before using real objects allows students to visualize the results of spatial actions (Battista, 1999). Thus, with prediction, students can become aware of misconceptions and solve them. It complements other forms of reasoning such as imagining, guessing, generalizing, and visualizing, helps direct students' attention to the relational and structural aspects of mathematics, and provides students with opportunities to experience cognitive conflict, notice patterns, generalize from specific situations, and expand the range of assimilation of a particular concept (Lim et al., 2010). In the *check* component, the students can discover their mental models' inconsistencies or consolidation by checking their predictions. Thus, they can verify the consolidation of their spatial manipulations and thus observe their reasoning (Patahuddin et al., 2020).

It is thought that students' level of internalization and use of knowledge increases in teaching with the VPC heuristic (Patahuddin et al., 2020). This research aims to reveal the effect of this heuristic in a computer-based teaching environment on students' spatial abilities. Although there are many researches in the literature using computer-based teaching, there are few studies on the VPC heuristic. This research is thought to contribute to the literature in this perspective. Thus, it is aimed to shed light on the teaching environments to be designed in the future by examining the development of students' spatial abilities with the mentioned heuristic in a computer-based environment.

For this purpose, this research focused on how the spatial abilities of 6th grade secondary school students developed in a computer-based environment (GeoGebra). The materials were designed to cover subjects such as motions of reflection, translation, and rotation, as well as views and expansions from different perspectives, included in the mathematics curriculum, using the VPC heuristic, which is thought to increase the student's internalization and use of knowledge. The research is essential in revealing the effect of computer-based environments in teaching geometry and measurement and determining the development of spatial abilities with the VPC heuristic.

In this sense, the research problem is handled as '*What is the effect of teaching in a computer-based environment and VPC heuristic on the spatial abilities of 6th grade students?'*

Method

Research Design

The experimental design, one of the quantitative methods, was used in the research. First, the Spatial Reasoning Instrument-SRI prepared by Lowrie et al. (2017) was applied to the students as a pre-test, and the students were divided into three homogeneous groups with the same characteristics. The groups were heterogeneous within themselves, and the students were at different levels in each group according to the scores of this test. In the first group, the education was only with the visualize component of the VPC heuristic. In the second group, the education was with visualize and predict components. Finally, in the third group, the education was with the visualize, predict and check components. After the teaching was completed, the SRI was re-applied to the students as a post-test, and the scores of students within the groups from the pre-test and post-test were statistically analyzed.

Research Sample

The research group consisted of 223 6th grade students studying in four public secondary schools in a large province of the Black Sea Region in the 2022-2023 academic year. In order to determine the research groups, firstly, SRI was applied to all students as a pre-test. According to the pre-test results, 75 students at different levels were randomly selected, and three groups were formed.

Three levels were determined according to the number of students' correct answers from the test result. 111 students who correctly answered 4-11 of the 30 questions in the test were at the first level; 95 students with 12-19 correct answers were determined as the second level, and 17 students with 20-30 correct answers were determined as the third level. Then, 75 students were selected randomly and distributed into three groups, with 25 students in each group. Thus, these three groups, in which the designed activities based on the computer-based and VPC heuristic would be carried out, were formed heterogeneously within themselves and homogeneously between the groups. In each group, the students were distributed proportionally according to their levels, and there were ten first-level students, ten second-level students, and five third-level students in each of the three groups.

Research Instrument and Procedure

In the research, the Spatial Reasoning Instrument (SRI) designed by Ramful et al. (2017) was used as pre-test and post-test to assess the students' spatial abilities. The test, developed to measure the spatial abilities of children between the ages of 11-13, is based on three-dimensional constructs: spatial visualization, spatial orientation, and mental rotation and consists of 30 questions. In the test, three-dimensional objects are drawn in a two-dimensional isometric form. The questions are about finding positions with the motions of reflection, translation, and rotation, determining cross-sectional area, expansion of prisms, and finding views of objects from different directions. The internal reliability value of the test was obtained as .845. The test-retest reliability was .81. The three-dimensional constructions were significantly correlated with well-established measurement instruments in the literature. These values were obtained as .71 for mental rotation, .41 for spatial orientation, and .66 for spatial visualization.

After applying SRI as a pre-test, activities with GeoGebra were designed according to the VPC heuristic and finalized by taking expert opinions. While designing the GeoGebra activities, which include the subjects of the motions of reflection, translation, and rotation, three-dimensional geometric objects and the expansions of these objects, and the view of geometric objects from different perspectives, the components of the VPC heuristic were taken into consideration. There is an example of the activities carried out in GGB according to the VPC heuristic:

- *Visualize component*

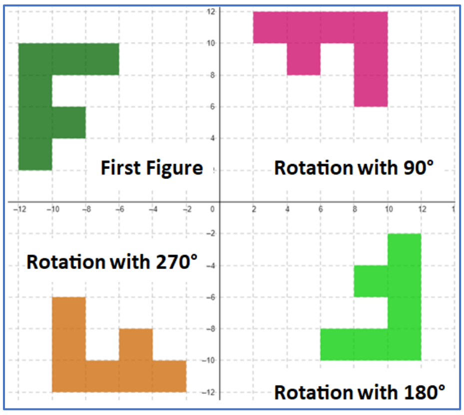

Figure 1. Visual of a sample for an activity in GeoGebra environment for the visualize component

In the visualize component, a polygon model and the motions of this model rotated 90°-180°-270° clockwise about the origin designed in the GeoGebra are shown to the students, respectively (Figure 1). During the visualization, the positions of the images formed as the result of the rotation of the first figure and the regions in the coordinate plane are examined.

- *Predict Component*

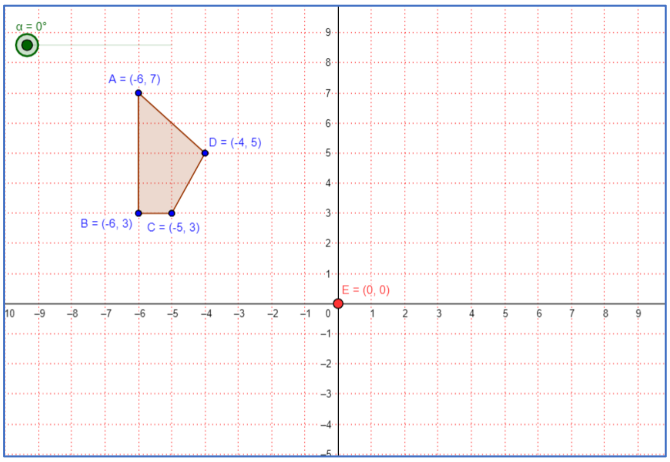

Figure 2. Visual of a sample for an activity in GeoGebra environment for the predict component

In this activity, students are asked to find where the image is when the given polygon is rotated 90°-180°-270° clockwise about the origin (Figure 2). Students are expected to comment on which regions and locations the polygon will be in. Students can construct the images that will be designed with GeoGebra on the interactive board, using the polygon tab of the software.

- *Check Component*

At first, students are expected to discuss their representations among themselves. Then, by specifying the angle in degree in GeoGebra, the rotation slider is moved, and the images of the first given polygon are constructed due to the rotation. Students are asked to compare and check their representations with the polygons constructed in GeoGebra. Students who represented the correct polygon are asked to explain what they took into consideration when constructing it.

Data Analysis

After the end of the instruction through the components of the VPC heuristic, SRI was re-applied to the students as a posttest. For the data analysis, the Shapiro-Wilk test was applied to check the normality of the distribution in the pre-test and post-test results, and the normality of the test was checked. To determine the change between the pre-test and post-test, a dependent t-test was conducted using the SPSS software, and the changes resulting from the instruction were observed

Results

In the research, the students determined in three levels were divided into three groups, and the t-test results of the instruction with the VPC heuristic were evaluated according to the groups. During the instruction with the visualize component, the visuals designed previously in GeoGebra were presented to the students. In this process, the closed and open forms of the objects were also presented in a static visual form, and the instruction was enriched with information about the subjects. The dependent t-test results of the pre-test and post-test scores of the first group students, who were instructed only with the activities of the visualize component, are given in Table 1.

Table 1. t-Test Results of Pre-Test-Post-Test Average Scores of the First Group

	N	$\bar{X}$	S	sd	t	p
Pre-test	25	13,36	5,51	24	-,778	,444
Post- test	25	13,52	5,41			

When instruction was only based on the visualize component of the VPC heuristic, it was observed that there was no statistical difference between the scores of the students in this group from SRI, as seen in Table 1, at a significance level of $p < 0.05$ ($t(24) = -.778$, $p > 0.05$). While the average SRI scores of the students before the instruction was $\bar{X}$=13.36, it was determined as $\bar{X}$=13.52 after the instruction.

While instruction was carried out according to visualize and predict components, the visuals designed previously in GeoGebra were first presented to the students. Like the first group, it was enriched with different examples and information about the subjects. In the predict component, different objects designed in GeoGebra were examined by the students, and they were asked to predict the new object formed as a result of motions or different views and to construct them on isometric or squared paper. The dependent t-test results of the pre-test and post-test scores obtained by the second group of students with this instruction are given in Table 2.

Table 2. t-Test Results of Pre-Test-Post-Test Average Scores of the Second Group

	N	$\bar{X}$	S	sd	t	p
Pre-test	25	14,20	5,94	24	-9,390	,000
Post-test	25	16,80	5,51			

When instruction was carried out according to visualize and predict components of the VPC heuristic, a significant difference was determined between the scores of the students in this group from SRI, as seen in Table 2, with a significance level of $p < 0.05$ ($t(24) = -9.390$, $p < 0.05$). While the average SRI scores of the students before the instruction was $\bar{X}$=14.20, it was determined as $\bar{X}$=16.80 after the instruction.

While instruction was carried out according to visualize, predict and check components, firstly, similar to the first two groups, the visuals designed previously in GeoGebra were presented to the students. Afterwards, it was enriched with different examples and information about the subjects. Then, similar to the second group, the students examined different objects designed in GeoGebra, and they were asked to predict the new object formed as a result of motions or different views and to construct them on isometric or squared paper. For the check component, it was first expected to discuss the students' representations among themselves, and then the images previously designed by GeoGebra were demonstrated. Afterwards, it was expected to check their representations by comparing them with the constructions designed in GeoGebra.

The dependent t-test results of the pre-test and post-test scores obtained by the third group of students with this instruction are given in Table 3.

Table 3. t-Test Results of Pre-Test-Post-Test Average Scores of the Third Group

	N	$\bar{X}$	S	sd	t	p
Pre-test	25	13,88	5,395	24	-10,947	,000
Post-test	25	19,32	4,679			

When instruction was carried out according to the visualize, predict, and check components of the VPC components, a significant difference was determined between the scores of the students in this group from SRI, as seen in Table 3, with a significance level of $p < 0.05$ ($t(24) = -10.947$, $p < 0.05$). While the average SRI scores of the students before the instruction was $\bar{X}=13.88$, it was determined as $\bar{X}=19.32$ after the instruction.

Discussion and Results

This research aimed to observe how the spatial abilities of 6th grade students developed with the VPC heuristic in a computer-based environment (GeoGebra) and to reveal the possible differences that may arise.

It was determined that in the first group, there was no statistically significant difference between the spatial ability test scores of the students when the instruction was only carried out according to the visualize component. Similarly, it was determined that there was no difference between the students' SRI average scores before and after the instruction. Considering that the visualize, predict, and check components specified in the heuristic are used in various ways and implicitly in teaching and learning, and the idea of Arcavi (2003) that visualization is a fundamental element of problem solving and reasoning, it can be suggested that activities carried out only with visualization cannot be sufficient to enhance the students' spatial abilities. This result is inconsistent in terms of only visualize component with Blüchel et al. (2013)'s opinion that targeted spatial skill training can increase children's mental rotation performance. It is also partially differs from Sanchez's (2012) idea of how improved visualization affects the individuals' spatial information process and how this cognitive change improves their test performance. However, as suggested by Lowrie et al. (2017), although these researchers did not examine the transferability of mental rotation instruction to other cognitive or motor skills, some researches have shown that training programs do not universally improve all spatial reasoning components. For example, they mention that while Taylor and Hutton's (2013) study stated that there was an improvement in spatial visualization, not in mental rotation, David's (2012) study demonstrated significant gains for low-ability students in mental rotation. In this sense, considering different components of spatial ability, it can be stated that this result of the research shows that instruction based only on visualization cannot serve the development of all dimensions of spatial skill, and it can be said that this result supports these mentioned ideas.

In the second group, a statistically significant difference was determined between the scores of the students on the spatial ability test when the instruction was according to visualize and predict components. Similarly, it was determined that there was a significant increase in the students' SRI average scores before and after the instruction. This result states that instruction according to visualize and predict components, contributes positively to the students' spatial abilities. In his research, Battista (1999) stated that making predictions before using real objects allows students to visualize the results of spatial actions. Similarly, Hegarty et al. (2003) stated that students' spatial skills tend to increase due to the activation of their prior knowledge through the prediction activity. The results obtained in the research on the instruction according to visualize and predict components support these researches in this sense. Moreover, considering the idea of Lim et al. (2010) about the students' predictions on the structural and relational perspectives of mathematics and their providing to notice patterns, generalize from specific situations, expand the range of assimilation of a particular concept, and experience cognitive conflict, it can be stated that the result of the research that instruction carried out with visualization and subsequent prediction contributes to the development of spatial abilities is consistent with this idea.

In the third group, a statistically significant difference was determined between the SRI scores of the students when they were instructed with visualize, predict, and check components. It was also determined that there was a significant and noticeable increase between the students' SRI average scores before and after the instruction. In this case, it can be stated that instruction according to visualize, predict, and check components contributes positively to the students' spatial abilities. The research ensured that students experienced multiple opportunities to visualize, predict, and check. In this way, the instruction was spatially significant when the instruction was according to all components of the heuristic, compared to instruction only according to visualize or visualize and predict components. Similarly, Patahuddin et al. (2020) stated in their study that instruction with the VPC heuristic improved spatial abilities.

Although the instruction was based on GeoGebra, the results generally demonstrate that differences in the components of the heuristic between the groups in the instruction led to differences in the development of the students' spatial abilities and their participation in the instruction. This result reflects the idea that compared to encouraging spatial thinking in instructions where all components of the heuristic are explicitly or deliberately implemented, instructions where this heuristic is implemented in a limitedly, tend to inhibit some opportunities for spatial reasoning (Patahuddin et al., 2020).

Recommendations

The VPC heuristic, which has spatially oriented content in teaching and learning, may offer the potential to improve spatial skills by routinizing it. For this reason, by implementing this heuristic to students in different age groups and grades, the spatial abilities of these students can be examined, and the dimensions of their spatial abilities can be focused on. In addition, considering that there are many factors affecting spatial ability, the effects of these factors can be examined in the instructions designed with the VPC heuristic in further research.

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