Chapter 4
Measuring Spatial Visualization: Test Development Study

Nazan Sezen Yüksel

4.1 Introduction

The innovations brought about by the present era provide various opportunities in every area including education. One of these innovations is to develop the abstract thinking skills and the creativity of students. When analyzed in this concept, the increase in the importance of spatial abilities concept and the increase in the studies on this ability has been inevitable. The importance of spatial ability, applied in many activities of daily life by individuals, is indisputable in scientific areas, especially in the field of mathematics.

The studies on spatial ability are based on different starting points. This situation has led to many different definitions and classifications about spatial ability. Labeling spatial ability by using different combinations of words like "visual", "spatial", "ability", "skill", "orientation" and "thinking" by many researchers and theoreticians on fields such as cognitive psychology, painting, science, mathematics and engineering is the most clear indicator of this (Miller and Bertoline 1991; cited in Mohler 2006).

Tartre (1990) identified spatial ability as a concept that contains spatial abilities like comprehension, manipulation, organization or interpretation of visual relations. Lohman (1993) mentioned different ability types that were identified by different viewpoints and determined spatial ability as retention, callback and transformation of visual pictures which are well-structured. Mayer and Sims (1994) have determined the spatial ability as envisioning of an object after situation changed, bent or rotated two or three dimensions of objects. Olkun (2003) identified spatial ability as a concept that contains skills about using geometric form and space usage. Towle et al. (2005) identified spatial ability as an ability to mentally represent the three

N. Sezen Yüksel (✉)
Hacettepe University, Ankara, Turkey
e-mail: nsezen.hc@gmail.com

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dimension forms of given two dimension objects. Velez et al. (2005) has determined the spatial ability as transformation, retention and arrangement the visual knowledge within spatial context.

According to Sternberg (1990) the spatial ability that an individual has is measured by an individual's ability to visualization figures, rotation of objects and determining the missing pieces of a puzzle. Furthermore, Linn and Petersen (1985) have associated this ability with the presentation, transformation, generalization and memorization of the symbolic knowledge which is unconnected with language.

In line with much identification about spatial ability, there are also many classifications about this ability.

It can be said that, the basic research for the studies about determination of the components of spatial ability belongs to Thurstone (1938, cited in Bishop 1980). Thurstone, examines the basic mental abilities in his study where he has determined the mental process ability about spatial or visual objects as a "space" factor. Zimmerman (1953, cited in Bishop 1980) on the other hand, has reanalyzed Thurstone's data and revealed two spatial factors. The first of these factors is similar to Thurstone's space factor and has been examined as the mental manipulations of the objects or object relations. Zimmerman has called this factor as "spatial relations". The second factor is named as "visualization". It is indicated that, the tests developed for visualization have a tendency to be slower and more difficult than tests which are developed for spatial abilities.

Guilford et al. (1952; cited in Pellegrino et al 1984) has applied 65 ability tests on 8000 aviation students and the data obtained have been evaluated by factor analysis. According to the results of this study, the spatial ability factors have been identified as having five factors as "Spatial relations, Visualization, Spatial Orientation, Spatial Scanning and Perceptual speed". The first two factors have been determined in literature as they applied. The spatial orientation factor is characterized as "emphatic involvement" which has been composed of spatial considerations of the individual given certain orientation. The Spatial Scanning Factor is interested with finding the correct route in a test like a labyrinth by using design instead of visual mapping. Ultimately, Perceptual Speed factor has been determined as the speed of the identification of the localization of the letter in the letter string.

Lohman (1979; cited in Pellegrino et al 1984) has reanalyzed the studies on factor analysis and concluded that spatial ability has two large sub-factors. These two sub-factors are spatial relations and spatial visualization factors. Lohman has asserted that both sub-factors can be evaluated by distinctive tests or problem types. Also it is indicated in this study that the difference between spatial relations and spatial visualization tasks can be shown by relations of different performance dimensions. One of these is speed-power dimension that the individual spatial relations problems should be solved more speedily than spatial visualization problems. The second dimension is to examine the stimulant and cognitive process complication. It is remarkable that the complexities of spatial relations problems have shown more differences amongst themselves although spatial visualization problems have included less complicated stimulants.

McGee (1979) has stated that, before 1930s studies about the demonstration of spatial factor characterization existence were going beyond showing the absence of spatial factor characterization. But after this year, the studies about factor works have proved and supported two different spatial abilities strongly which were determined as “visualization and orientation”. Based upon these studies, McGee has, determined the visualization ability as “overturn, doubling and the ability of mental manipulation of a stimulant object shown as pictorial”. Also a different classification of spatial ability has been given by Linn and Petersen (1985). According to their classification; the sub-categories of spatial ability are signified as: spatial perception, mental rotation and spatial visualization. Gorska et al. (1998) has approached spatial ability as comprising of five components. These components are “spatial perception, spatial visualization, mental rotation, spatial relations and spatial orientation”.

According to recent studies, Allen (2003, cited in Yılmaz 2009) has grouped the spatial ability under three functional families. The determining object (answered the “what is this?” question); finding the place of object (answered the “where is it?” question); and mobile orientation (answered the “Where am I?” question). Carroll (1993) has scanned the studies about factor analytic in the literature and in his study; he has distinguished the components of spatial ability as having five dimensions like: spatial visualization, spatial relations, closing speed, closing flexibility and perception speed.

Spatial visualization, which is included in these classifications, is defined as one of the most important sub-dimensions of spatial ability. Just like spatial ability, spatial visualization is mentioned in numerous aspects in the literature. More importantly, it is observed that spatial ability and the concept of spatial visualization are used interchangeably in some studies. McGee (1979) defines spatial visualization as a subset of spatial skills which includes “the ability of mental manipulation, rotation, bending or to translate the inverse image of an object shown in the stimulus”. Fennema and Tartre (1985) define spatial visualization as “spatial ability tasks which require complex multi-step manipulations of information shown as spatial”. Carroll (1993) denotes spatial visualization as comprehension, coding and the mental manipulation process of three-dimensional images. According to Carroll, spatial visualization tasks require a connection in the direction from two-dimensional to three-dimensional images and in the opposite direction. Lappan (1999), however, describes visualization as “the mental coupling of visual information.” Olkun and Altun (2003) describe spatial visualization as the ability to create a mental picture of new conditions resulting from moving of two-dimensional and three-dimensional objects and their components in space.

4.1.1 Tests on Spatial Visualization Ability in the Literature

Different definitions on spatial visualization ability have caused this ability to be measured by various types of tests. As an example, Yue (2006) used Purdue Spatial Visualization Test (PSVT) in his study. Purdue Spatial Visualization Test was originally developed by Guay in 1977. In this test, there are questions regarding to

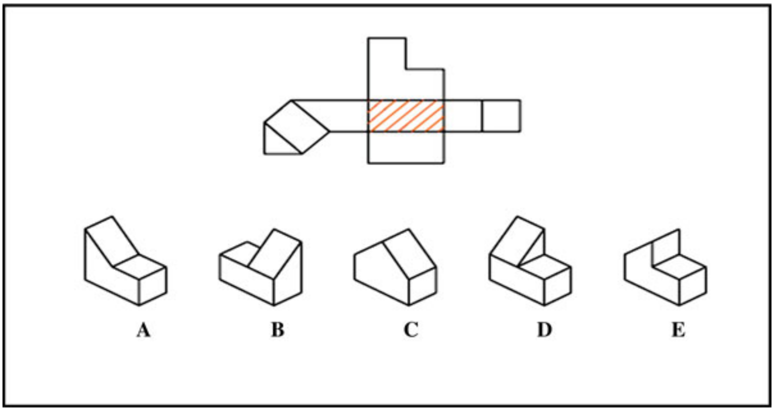

Fig. 4.1 A sample question for Purdue Spatial Visualization Test

three-dimensional surface models developed by folding two-dimensional flat-patterns (Fig. 4.1).

The test asks to determine the closed form of the object out of its opened form given above.

Linn and Peterson (1985) indicated in their studies that they used Embedded Figures and Paper Folding tests to determine the ability of spatial visualization. The Embedded Figures Test was developed by Witkin et al. (1977) to identify how the perception of an item by an individual is affected by the form it is in. The test consists of three sections. In the first section, the aim is to prepare the individual with seven figures for the initial stage of the test. This section is not taken into account in the assessment part as its aim is for preparation only. In the second and the third sections, there are 18 questions which require the detection of simple figures inside given complex figures (Fig. 4.2).

In the sample question about Embedded Figures test, the participants are required to find each figure above from the complex figures given beneath.

Paper Folding test was developed by French et al. (1963). The task of the students in this test is to determine the shape of the paper folded and punched on different points after it has been opened (Fig. 4.3).

In the above paper folding test, participants are asked to identify the unfolded form of the paper given as folded.

A different version of Paper Folding Test was developed by Kyllonen et al. (1984). In this test, the participants are asked to discover the opened final shape of a piece of square paper folded one or more times and punched on the folded parts (Fig. 4.4).

In this different version of paper folding test, participants are required to answer questions similar to the ones above and also to identify the opened form of a piece of paper folded once or more times and punched on the marked points.

Another spatial visualization test in the literature is "Dailey Professional Test (1965)" (Eliot and Smith 1983). In this test, the open and closed forms of figures are

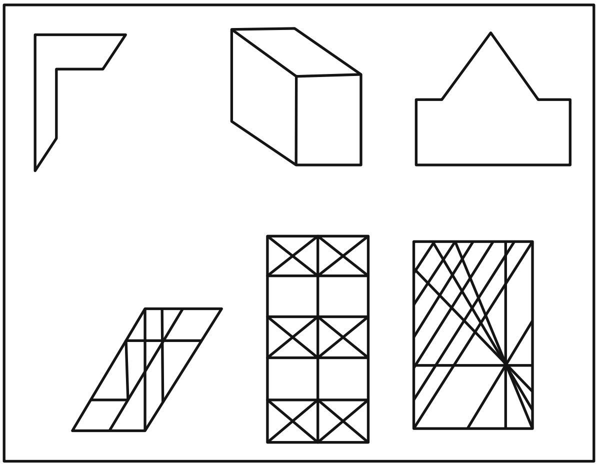

Fig. 4.2 A sample question for Embedded Figures Test

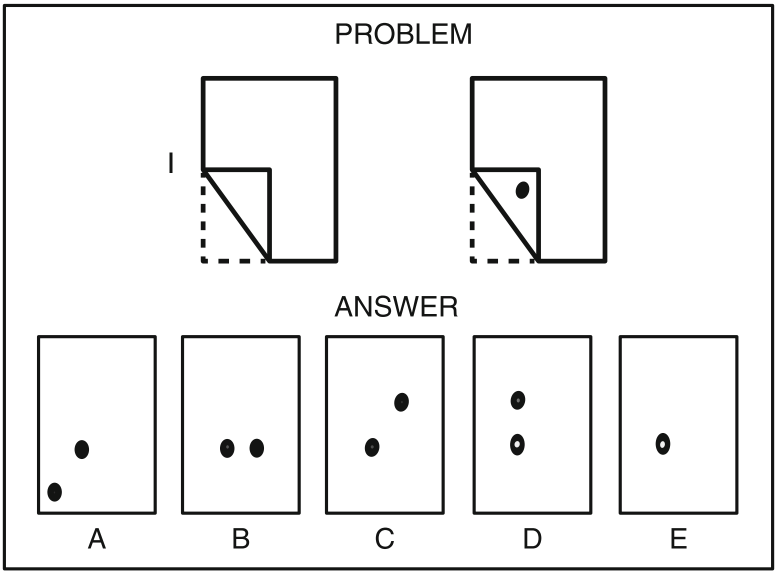

Fig. 4.3 A sample question for Paper Folding Test (French et al. 1963)

given and the participants are asked to match the forms of identical figures looking at their opened and closed forms. In Monash Spatial Visualization Test (1977), however, there are questions about cube formation and comparisons of various lengths (cited in Eliot and Smith 1983) (Figs. 4.5 and 4.6).

The question gives a diagonal of the object and asks participants to identify how many cubes having the same diagonal can be created.

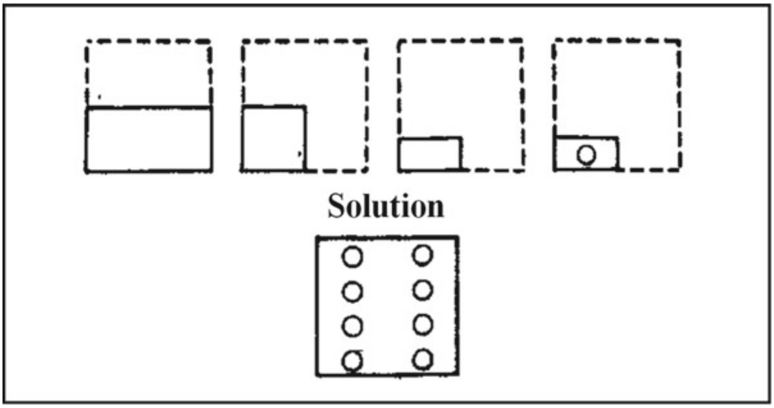

Fig. 4.4 A sample question for Paper Folding Test (Kyllonen et al. 1984)

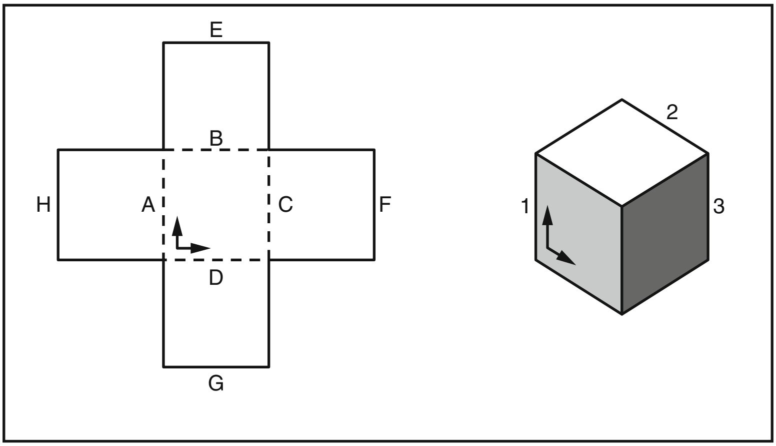

Fig. 4.5 A sample question for Dailey Professional Test

The last example for spatial visualization tests is the test of "Middle Grades Mathematics Project: Spatial Visualization". This test was prepared for the project called "Middle Grades Mathematics Project" conducted in U.S.A. for middle grades at primary education and then developed by Winter et al. (1989). The test consists of 15 questions. There are five choices for each question. In addition to the isometric appearance of structures composed of unit cubes, test questions include questions regarding these structures' view from right, left, front and back. Moreover, in this test, there are questions about MAT plans which constitute the special code of the view of the structures from above (Fig. 4.7).

In the question, given the front right view of a figure participants are asked to identify the rear view of the same figure.

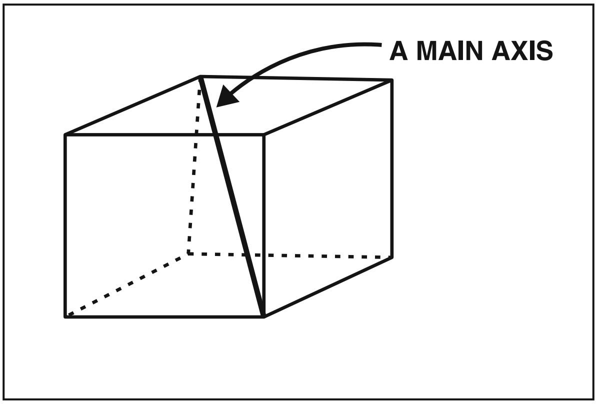

Fig. 4.6 A sample question for Monash Spatial Visualization Test

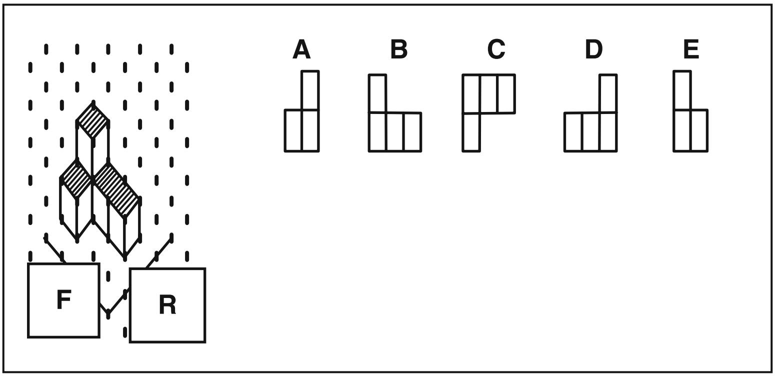

Fig. 4.7 A sample question for Middle Grades Mathematics Project: Spatial Visualization Test

4.1.2 Activities Performed to Develop the Spatial Visualization Ability

Christou et al. (2007) defend the necessity of dynamic and interactive computer applications holding the features of appropriate 3D objects to develop 2D and 3D spatial visualization and reasoning abilities. For this aim, they emphasize that the visual conception of students can be enhanced with the help of dynamic geometry software (Cubix Editor) they have created.

In their studies, Rafi et al. (2008) conducted research on the effects of instructional method on spatial visualization ability. Within the scope of the study, students were divided into three groups consisting of two experiment groups and one control group. While the first experiment group was trained with interactive-based and the second experiment group in an atmosphere developed by animation-based methods, the control group was trained with traditional methods. At the end of the study, they concluded that the most progress was achieved through interactive-based methods; average progress was made in an animation-based atmosphere, whereas no progress was made with traditional methods.

In addition, in another study, Rafi et al. (2006) have shown that spatial visualization ability can be developed by computer-aided engineering drawing. For the development of this ability, Interference Engineering Drawing (EDwgT) education and two types' conventional techniques have been applied. In one of these conventional techniques, written materials have been used by utilizing digital videos. In the second technique, written materials have been used without any enhancing effect. According to the findings obtained; the spatial visualization ability of students which have been applied EDwgT education, has not shown meaningful increase.

In his semi-experimental study with graphic engineering students, Gillespie (1995, cited in Idris 2005) investigated the effects of education with three-dimensional models on the development of three-dimensional visualization abilities. During a 10-week training period, students were trained with three-dimensional modelling training prepared, within the scope of the study. According to the results of the analysis obtained from tests which were applied during the assessment process, a significant increase was observed in the visualization abilities of experiment group compared to other groups.

Robinson (1994) in his study carried out with seventh class students, has examined the relationship between spatial visualization ability, mathematical ability and problem solving strategies, by Geometer's Sketchpad software. Cube Comparison, Card Rotation and Paper Folding tests have been used as measurement tools in this study. The group, which used Sketchpad software, was specified as the experiment group whereas the other group not using this software was specified as the control group. Both groups have been trained by geometry lecture. According to the results; the spatial visualization and active participation to educational activities performances of the students that have been educated by technological support have increased.

Cohen and Hegarty (2008) have designed two different experiments in their study with the aim of development of the spatial visualization abilities of the students. They have used animations that show the surface of the sections by cutting a section of the regular three dimensional shapes like pyramids, prisms, cylinders, cubes and cones that drawn by 3d Max. After both experiments it has been concluded that the spatial visualization ability can be developed by education and, in this education, interactive computer visualizations are quite useful.

Takahashi (2011) has computerized "Purdue Spatial Visualization Test: Rotations" test by using 3d Max software. With this software, Takahashi has defended that he can increase the depth of visualization for students better and he observed at the end of the study that the levels of spatial visualization ability of the students with low ability have shown increases after the application of the three dimension environment.

4.1.3 The Importance of Spatial Visualization Ability on Mathematical Area

Another area where spatial ability is often applied is mathematics. It is due to the fact that the identifications and functions of both spatial ability and its sub-dimensions are found to play a significant role in mathematics as well. In support of this claim, Halpern (2000), has emphasized that mathematics requires spatial ability because of both its subjects (geometry, topology, trigonometry, etc.) and its nature. Also Krutetskii (1976; cited in Idris 2005) has indicated that spatial visualization was a kind of mathematical ability and he has also professed that this ability was not an inborn attribution like mathematics, but rather it could be restructured by improvement. The common results received from different studies show that the deficiency of basic visualization skills of some students causes them to perform below expectations (Clements 1998; Del Grande 1987).

Sundenberg, in 1994, conducted studies in a summer school mathematics project with a 34 student sample comprising of six to eighth class students, with the intention of determining the effect of spatial education and geometry education on spatial performance and mathematics success. In this study, students have been separated into four groups randomly. Concrete materials were given to Spatial Group 1 and 2 to develop their spatial visualization skills; Geometry Group 1 and 2 were educated traditionally by using 8th class math book. All students had training in geometric concepts education for 25 h. Both before and after training, a mathematics achievement test and Secondary Education Mathematics Project Spatial Visualization test were applied to all students. According to the findings, the spatial visualization abilities of Spatial Groups increased more than Geometry Groups. However, neither of these groups showed an increment on mathematics success test results (Idris 2005).

Idris (2005) has examined the importance of cognitive variables of spatial visualization ability on geometry success and the effect of chosen educational activities on spatial visualization and geometry success in his study. In educational activities, shapes have been given for the questions in the Spatial Visualization Test (SVT) to the students. According to obtained results of the study, a significant correlation as .56 level between spatial visualization ability and geometry success was found. Also, it has been found that the educational activities have positive effect on the spatial visualization ability.

Presmeg (2006) has indicated that mathematics is a subject that has diagrams, tables, spatial arrangements of signifiers such as symbols, and other inscriptions. Hence, spatial visualization is one of the important basic abilities in learning and studying mathematics.

Van Garderen (2006) has expressed that there is an important difference among those who use visualization skills to solve math problems, those who use "schematic imagery" and those who use "visual imagery". Schematic problem solvers use spatial relation in their visualizations and diagrams, while those who only use visual identifications do not. This research results show to confirm the notion that there exists such a distinction between schematic imagery and visual imagery.

4.1.4 The Importance of Spatial Visualization Ability for Other Disciplines

The spatial visualization ability's relation with many branches is mentioned as a research topic for the studies in different disciplines. These studies have a wide range like painting, education, science and engineering fields.

Many studies, emphasize the importance of spatial visualization ability by indicating that this ability is a presupposition for science subjects. Furthermore, a significant relationship between success on science branch and spatial ability has been shown in these studies (Aris et al. 2010).

Kozhevnikov et al. (2007) have examined the relationship between spatial visualization and solving physics problems in their study. For this purpose three works on kinematic problems have been prepared by researchers and their relationships have been examined. In the first work, the estimation of the two dimension movies of an object was explored, in the second work the transition from a reference (an observer) to another one, and in the third work the skill of explaining of kinematic graphics and spatial visualization abilities have been analyzed. According to the findings obtained from research, it is concluded that; spatial visualization has a meaningful correlation with kinematic problem solving in Work 1 and Work 2. Work 3 also verified this relationship as strong and meaningful.

Macnab ve Johnstone (2010) has expressed that spatial tests do not dependent on biology knowledge but these tests have indicated the necessary abilities for the biology. They have specified these abilities as follows:

- The visualization ability of two dimension sections taken from three dimension structures
- The visualization ability of three dimension structures composed from given two dimension section
- The ability to distinguish the change in orientation of a structure

These studies have found that there is a relationship between spatial visualization in genetic lectures and the success for the learning of genetic concepts like as dihybrid crosses, meiosis, Hardy-Weinberg theorem, peptide bonds occurrence and nitrogen base/amino acid relation (Costello 1985, cited in Lennon 2000).

Wu and Shah (2004) have examined the structural relational research about chemistry education and spatial visualization their study. For this purpose, they have researched the studies published on different databases in 1966–1987 and they have pointed out the positive correlation between spatial visualization ability and success on chemistry education.

4.1.5 The Analysis of Spatial Visualization Ability in Relation to Gender

It has been revealed through a number of studies that spatial visualization ability differs significantly in relation to gender and it is in favor of males. For instance, the results of research conducted by Rafi et al. (2008), express that the spatial visualization ability of men is higher than that of women. However, Eisenberg and McGinty (1977), according to their study for university students registered on two different mathematics programs (calculus and occupation statistics), female students have higher spatial visualization performances than male students.

In a study analyzing the mathematical performance and different cognitive abilities in relation to gender, Maccoby and Jacklin (1974) came to a conclusion that spatial visualization significantly differs in favor of male students. In addition, the identification of the fact that this difference is not present at primary education, but arises during the adolescence period, is another important result of the study.

McGee (1979) mainly presents four reasons for the difference in spatial visualization ability according to gender. These reasons are environmental, genetic, hormonal and neurological factors. The factors mentioned related to hormones result from estrogen and androgen hormones. In the scope of McGee's study, it was discovered that high levels of androgen hormone signifies low level of spatial ability. Another factor expressed under the heading of neurological factors is related to the development of brain hemispheres.

Deno (1995) has indicated that there is a direct relationship between spatial visualization ability of engineering students and spatial experiments which are not concerned with academic subjects. Additionally, Deno has emphasized that spatial experiments differ greatly according to gender. As a proof of this situation he has shown that, during the bloc setting of toy types, male students use visualization but female students consult touching activities mostly.

As opposed to the studies in the literature which support that spatial visualization differs significantly in relation to gender, there are also some studies that claim the opposite. In the study which investigated the solution strategies and gender variables in spatial visualization tasks, Burin et al. (2000) proposed that there is no significant difference in spatial visualization tasks in relation to gender. Similar results were also found in Linn and Peterson's (1985) studies. According to the aforementioned study, the difference of spatial visualization ability among genders is very little or non-existent.

4.1.6 The Aim of the Study

The aim of this study is to develop a new spatial visualization test involving mathematical context different from tests in the literature. Questions in different categories were prepared on the basis of other spatial visualization tests analyzed with this purpose. By requiring the establishment of a relationship between three-dimensional figures with curves and by rotating these curves around axes in the categories created according to the purpose of this study, a different approach is taken towards spatial visualization.

4.2 Methodology

In this part of the study, there is information on the assessment tool and the development stage. This study is a test development study. Downing (2006) has organized 12 steps for developing an effective and efficient test as follows;

- Overall plan: construct, desired test interpretations, test format, clear purpose…
- Content definition: sampling plan for domain, various methods related to purpose of assessment,
- Test specifications: operational definitions of content, framework for validity evidence related to systematic…
- Item development: development of effective stimuli, formats …
- Test design and assembly: designing and creating test forms …
- Test production: publishing activities …
- Test administration: validity issues concerned with standardization …
- Scoring test responses: validity issues, quality control …
- Passing scores: establishing defensible passing scores …
- Reporting test results: validity issues; accuracy …
- Item banking: security issues, usefulness …
- Test technical report: systematic, detailed documentation …

In consideration of given items, according to expediency level of purpose, the following processes have been made for the composition of each item's content.

4.2.1 Preparing the Test Items

The "Spatial Visualization Test" has been designed as six parts to be used in this study by researcher. The expectation from a student who performs acceptably in this test are as follows:

- Can determine the three-dimension form of geometric shapes after they are rotated around an axis of two-dimension geometric shapes.
- Can determine the three-dimension shapes resulting from which two-dimension shapes after rotating around any axis.
- Can identify the close state of a three-dimension object from a given open state.
- Can identify the open state of three-dimension object from a given close state.

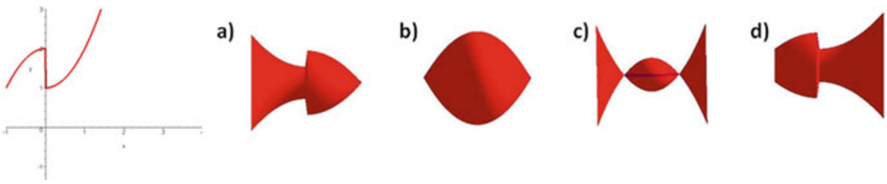

Fig. 4.8 A sample question for the first category

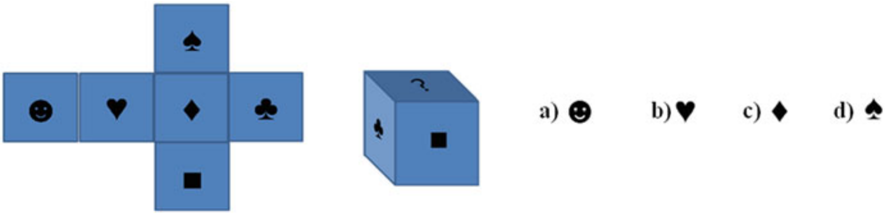

Fig. 4.9 A sample question for the second category

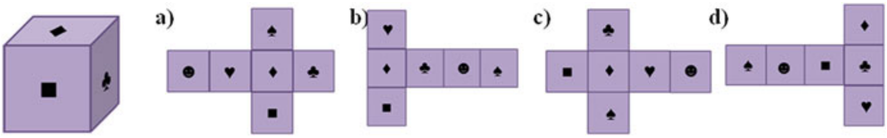

Fig. 4.10 A sample question for the third category

At the beginning of the test development stage, questions in 6 categories were prepared trough an analysis of spatial visualization tests in the literature. In the first of these categories, students are asked to determine the possible three-dimensional shape which will be formed by the rotation of a planar curve around the x- or y- axis (Fig. 4.8).

The question which is given as a sample above requires the participant to choose the correct image of a three-dimensional object of the curve which is created after rotation around the x-axis.

In the second category, there is an open cube with shapes on all sides and the students are asked to identify the possible shape on any blank side of the cube after being closed (Fig. 4.9).

Contrary to the second category, in the third category students are asked to identify which option cannot be represent the opened form of the cube (Fig. 4.10).

The questions in the fourth category are designed to identify the closed form of non-uniform shapes when folded. The questions here were employed from the test called "Differential Aptitude Tests (DAT)" developed by Bennett et al. (1974) (Fig. 4.11).

Finally, as opposed to the first category, in the questions of the fifth and sixth categories, the students are presented with a three-dimensional shape and expected to identify from which planar curve rotating around the x- or y-axis respectively the three-dimensional shape has been formed (Fig. 4.12).

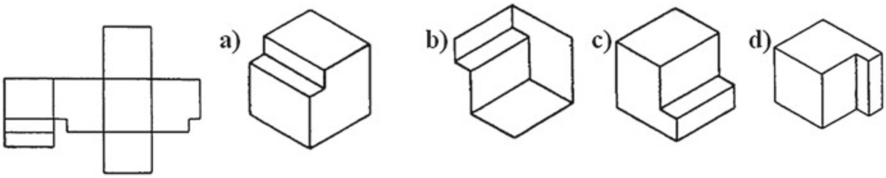

Fig. 4.11 A sample question for the fourth category

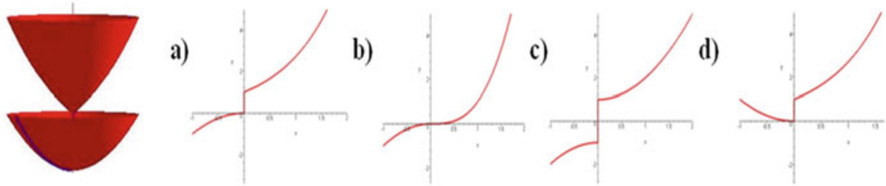

Fig. 4.12 A sample question for the fifth and sixth categories

4.2.2 The Pilot Application of Prepared Test

The test was piloted with 236 students studying on mathematics and mathematics education programs at two state universities in Türkiye. In the literature it has been emphasized that the pilot application group must be comprised of at least a hundred people and it would be been more realist if the group is comprised of around 200 people (Baykul 2000).

There is no demographic information section in this test since the academic standing and class levels of students have not been considered. The factor that is emphasized most during pilot application process was "time limitation". In the literature on some studies about spatial ability and its components, it has been indicated that time limitation has played a significant role disabling the students to display their real performance (Goldstein et al. 1990; Cherney and Neff 2004). Due to these reasons, there was no time limitation to students during the process of pilot application of this test.

4.2.3 Analysis of Obtained Data

Following the preparation of items in the test, some changes were made in both the forms and question statements of these items in accordance with the opinions of experts. The pilot application of the test has been applied in this form, and using the data obtained from this pilot application, item analysis and then validity and reliability analysis have been undertaken.

The item analysis of the items in the test from the pilot application has been performed with Iteman 3.5 statistics software. From the item analysis of the test, item difficulty coefficient and item discrimination index for each item has been obtained. As a criterion to comment on the item discrimination index, the values designated by Ebel (1965; cited in Crocker and Algina 1986) have been used. According to this, the item discrimination index is;

- Items on 0.19 and below can absolutely not be put in the test.
- Items between 0.20 and 0.29 are liminal items and if necessary, they can put in the test after rectification.
- Items between 0.30 and 0.39 can be put in the test without rectification or with minimal rectification.
- Items on 0.40 or greater are well processor items and can be put in the test exactly the same.

With regard to the Item Difficulty Factor, the items mostly with middle difficulty (approximately 0.50) are preferred in order to be suitable for the purpose of test. However, whether the item difficulty indexes have normal discrimination or not, has been determined in consideration of the suggestions in the literature (Baykul 2000).

For the test reliability study, in consideration of data obtained from pilot application, Cronbach Alfa has been used based on internal consistency method. Khaing et al. (2012) have not chosen test – retest reliability method due to the risk of participants remembering the items in the second application since spatial ability tests are generally comprised of shapes. Due to the same concern, in this study it has been deemed sufficient to calculate the internal consistency by Cronbach Alpha, which is based on one application. To determine the reliability of the developed test, reliability analysis using SPSS 17.0 software has been conducted.

A criterion related validity method has been used for the test validity in this study. In this study, another criterion is a test that admitted measurement as spatial visualization ability in the literature. Both the application of the test in literature and the test developed for this test are applied to the same group and the correlation of the points obtained from the two tests have been determined. Another process used as a proof of validity for the test is to determine if some results of spatial visualization in the literature are also obtained from the developed test or not. Therefore; the result determined has been that, in the literature the differentiation of spatial visualization ability on the basis of gender is meaningful. In addition, as the proof of the validity of the study, the last process is confirmatory factor analysis. The confirmatory factor analysis of the data obtained from applying the test has been performed with Lisrel 8.7 statistics software. For the interpretation of the findings obtained from confirmatory factor analysis, fit indices criteria determined by literature have been considered. The criteria of fit indices and cut points for acceptance as follows (Çokluk et al. 2010) (Table 4.1):

Table 4.1 Fit indices criteria for confirmatory factor analysis

Fit index	Criteria	Cut points for recognition
X^2/sd	p > 0.05	≤2 perfect fit
		≤2.5 perfect fit
		≤5 moderately fit
GFI/AGFI	0 (no fit)	≥0.90 well fit
	1 (perfect fit)	≥0.95 perfect fit
RMSEA	0 (perfect fit)	≤0.05 perfect fit
	1 (no fit)	≤0.06 well fit
		≤0.07 well fit
		≤0.08 well fit
		≤0.10 weak fit
RMR/SRMR	0 (perfect fit)	≤0.05 perfect fit
	1 (no fit)	≤0.08 well fit
		≤0.10 moderately fit
CFI	0 (no fit)	≥0.90 well fit
	1 (perfect fit)	≥0.95 perfect fit
NFI/NNFI	0 (no fit)	≥0.90 well fit
	1 (perfect fit)	≥0.95 perfect fit

4.3 Findings

The findings related to the item, validity and reliability analyses of Spatial Visualization Test developed within the scope of the research is as follows:

4.3.1 The Findings of the Item Analysis on Spatial Visualization Test

According to the item analysis results, the difficulty level among items is identified as 0.27, minimum and 0.66, maximum. The values of other items range from 0.34 to 0.72. With this information, the difficulty level of the test can be accepted to be average.

Item difficulty factors for 29 items and One-Sample Kolmogorov-Smirnov test have been realized based on whether item difficulty indexes have shown normal distribution or not. The results of this analysis are as follows:

Table 4.2 One-sample Kolmogorov-Smirnov test for item difficulty

		İtem difficulty coefficients
N		29
Normal parameters	Mean	.4324
	Std. deviation	.10534
Most extreme differences	Absolute	.080
	Positive	.064
	Negative	–.080
Kolmogorov-Smirnov Z		.429
Sig (2-tailed)		.993

Table 4.3 The results of the item analysis

Number of items	29
Number of examinees	236
Mean	19.86
Standard deviation	5.697
Skewness	–0.755
Kurtosis	0.383
Mean item difficulty	0.492
Mean item discrimination	0.573

As is seen in Table 4.2; the relevance value is found as .993 for Kolmogorov-Smirnov test.

In terms of discrimination level of items, the coefficient of the lowest item is 0.24, while the highest is 0.64. The values related to other items range from 0.31 to 0.61. The results of this analysis are presented in Table 4.3.

4.3.2 The Findings Related to the Reliability of Spatial Visualization Test

The items developed for the test were graded in accordance with answers as 1-0 dichotomously. During the reliability test of data collection tools, the internal consistency of coefficient of Cronbach α was taken into consideration. Although the obligation of using KR-20 technique in dichotomous grading is emphasized in the literature, it is known that when all items are graded as 1-0; KR-20 and the coefficient of Cronbach α have the same results (Cronbach 1951). Cronbach α coefficients belonging to the spatial visualization test developed within the scope of the study was found as .84.

4.3.3 The Findings Related to the Validity of Spatial Visualization Test

In this part, there are studies conducted to prove the validity of spatial visualization test. To find evidence for the construct validity of the study, the correlation between the spatial visualization test and another test accepted to evaluate the same ability was searched. In addition, it was checked whether or not the features identified in research were also obtained in the test developed for the study.

To find evidence for the construct validity of spatial visualization test (SVT), "Spatial Visualization Test (SVT*)" developed by Winter et al. (1989) was applied to 128 students in the research group. The data obtained from the application of these two tests to the same work group have been used in a correlation analysis using SPSS 17.0 software. The findings according to result of analysis are as follows (Table 4.4);

According to the results of the analysis, a significant positive correlation at the level of .66 was found between the Spatial Visualization Test developed for the study and the Spatial Visualization Test developed by Winter et al. (1989).

In the other part of the reliability test, the focus was on the question of whether the results from the tests applied in the literature were valid for the test developed for this study or not.

In their studies, Vandenberg and Kuse (1978) and Hamilton (1995, cited in Alias et al. 2002) expressed that men's spatial visualization abilities are at higher level compared to women's. Ben-Chaim et al. (1989), in their studies, concluded that

Table 4.4 The correlation analysis between the SVT* and SVT

		SVT*	SVT
SVT*	Pearson correlation	1	.667**
	Sig (2-tailed)		.000
	N	128	128
SVT	Pearson correlation	.667**	1
	Sig (2-tailed)	.000	
	N	128	128

**Correlation is significant at the 0.01 level (2- tailed)

Table 4.5 The analysis of the spatial visualization test in accordance with gender

	Levene's test for equality of variances	t-test for equality of means					
	F	Sig.	t	df	Sig (2-tailed)	Mean difference	Std. error difference
Equal variances assumed	2639	.106	–11.540	229	.000	–7.357	.638
Equal variances not assumed			–10.995	134.1	.000	–7.357	.60091

male students have better spatial visualization abilities than female students. Similar results can be seen in the studies of Baenninger and Newcombe (1995).

To identify whether there is a difference according to gender in the test developed for this test and find out for with which group the ability is better, if there is really a difference, independent sample t-test was applied. The results of the analysis obtained for both tests are as follows:

According to the results of the analysis in Table 4.5, it is seen that the spatial visualization test developed for the study shows significant difference depending on gender and more importantly this difference is in favor of male students.

4.3.4 The Findings Related to the Confirmatory Factor Analysis

The last step performed to prove validity is Confirmatory Factor Analysis. For the application of confirmatory factor analysis, one of the factoring techniques of Maximum Likelihood Factor Analysis is used. This technique, developed by Lawley in 1940s, estimates the values of the research population for the factor loads on the possibility of the highest calculated load values of the correlation matrix sample captured and observed from the research population. The Maximum Likelihood Factor increases the canonical correlation between factors and variances to the highest size (Tabachnick and Fidel; cited in Çokluk et al. 2010). An important advantage of this analysis is that it provides opportunities for statistical evaluations related to how it is possible to make better factor analysis to reorder the relationships among indicators in the data set (Çokluk et al. 2010). However, Maximum Likelihood Factor Analysis requires the assumption of a multi-variable normal distribution for variables and if the data set does not meet this assumption, it may lead to a distorted and non-valid result (Brown 2006; cited in Çokluk et al. 2010).

Based on this information, whether or not the data obtained from the application of this test met the assumption of normality was analyzed before the confirmatory factor analysis which would be applied to the data collection tool in the study (Table 4.6).

As the obtained values of p is >0.05 when the results of One Sample Kolmogorov-Smirnov Analysis are studied, it is determined that the data obtained from this test verifies the assumption of normality.

The conformity indices obtained as a result of the verification factor analysis carried out after determining normality assumption are as follows (Table 4.7):

It has been considered appropriate that, according to modification suggestions which have been obtained from analysis results, the cause of significant contributing to χ^2; removing the 8. and 16. items from the test and, besides, connecting 6. and 7. items to each other. According to this fit indices in final position have been obtained as CFI = 0.97, RMR = 0.014, GFI = 0.90, NNFI = 0.96 and RMSEA = 0.032. The determination of the obtained fit indices have pointed that NNFI = 0.96, RMR = 0.014, CFI = 0.97 and RMSEA = 0.032 indices to perfect fit for this model,

Table 4.6 The analysis of spatial visualization test related to the assumption of normality

		t
N		235
Normal parameters	Mean	15.40
	Std. deviation	6.427
Most extreme differences	Absolute	.075
	Positive	.075
	Negative	–.047
Kolmogorov-Smirnov Z		1.154
Sig (2-tailed)		.139

Table 4.7 The confirmatory factor analysis for the spatial visualization test

	Goodness of fit statistics
Comparative Fit Index (CFI)	0.91
Root Mean Square Residual (RMR)	0.015
Goodness of Fit Index (GFI)	0.86
Non-Normed Fit Index (NNFI)	0.93
Root Mean Square Error of Approximation (RMSEA)	0.042

GFI = 0.90 to well fit (Hooper et al. 2008; Sümer, 2000; Jöreskog and Sörbom 1993, cited in Çokluk et al. 2010).

The path diagram after the application of confirmatory factor analysis is as follows (Fig. 4.13).

4.4 Results and Conclusions

Although there have been a large number of research studies on spatial ability and its components in which different definitions and different assessment tools have been developed, the common point these studies unite is the importance of this ability.

The spatial visualization ability is one of the most important components of spatial ability and has many areas of utilization in many disciplines. It also increases success of each discipline. But in literature research, the point which draws the most attention in these studies is the fact that although participating students have different features, they are assessed with the same test (Khaing et al. 2013; Mäntylä 2013). Therefore, the results obtained from studies being comparable with each other or making inferences from these studies seem possible. This situation has been seen as a cause for developing the spatial visualization tests, just as the subject to this study.

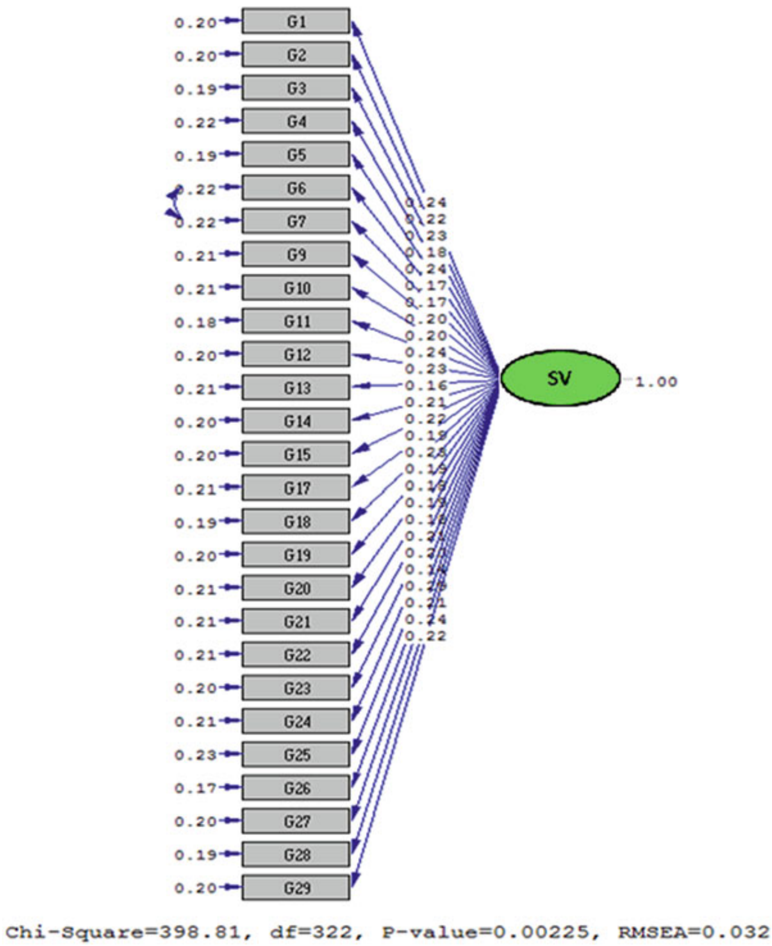

Fig. 4.13 The path diagram for the spatial visualization test

Considering this situation as the starting point of this study, the study aims to identify the spatial visualization abilities of students studying mathematics or mathematics education with field-specific questions as well as classical spatial visualization questions. Thereby, the test developed within the context of this study diverging from and the tests in literature, the undergraduate students have been determined as target group by the test that includes mathematical context.

In the first step of test developing, the spatial visualization tests in the literature and others of these tests, the tests for the other components of spatial ability like mental rotation, mental cutting and spatial orientation have been researched. The aims of researching the tests for other abilities is (1) to make a perception about what is the characteristic difference of this ability from the other ability types and (2) to prepare the items in the test to be developed according to this content. The target behaviors have been determined that will be measured by the developed spatial visualization test as a result of researching related literature.

According to this; the expectations from a student who capable of doing this test can determine the three-dimension form of geometric shapes after turned around axis of two-dimension geometric shapes, can determine the three-dimension shapes that become which of two-dimension shapes after turn around any axis, can identify the close state of three-dimension object which given open state and can identify the open state of three-dimension object which given close state.

In accordance with determined source behaviors, the spatial visualization test developed for this aim and consisting of 29 questions was introduced with a study applied to 236 undergraduate students studying mathematics and mathematics education at two different universities. As a result of the reliability analysis, the Cronbach alpha coefficient was found as .84. According to this, it can be said that the reliability of the test is at a high level (Salvucci et al. 1997).

For the purpose of supporting a proof for the validity of the test, the test was compared to another test (Winter et al. 1989) in the literature and is accepted to test the same ability by studies. A significant positive correlation level .66 was observed between the data obtained from the application of the two tests. Both tests also showed the same properties when gender factors were taken into consideration. With the help of the data, the validity and reliability of the test were tried to be proven.

In the other part of validity study of the test, it has been examined that if both tests have had the same properties with regards to the determined variable or not. At this stage, the variable to be examined has been approached as “gender”. In the literature many studies have shown that the spatial visualization ability has shown meaningful difference according to gender. Furthermore it is concluded that this difference is in men’s favor (Rafi et al. 2008, Maccoby and Jacklin 1974; Rafi and Samsudin 2007). As a result of the application of t-test statistical analysis of the data obtained from the test which was developed for this study context, it has been concluded that spatial visualization ability has shown meaningful difference and this difference is in men’s favor. These results show consistency with literature, it can be shown as a proof for test validity.

The fit indices obtained from the confirmatory factor analysis of spatial visualization test have been found in the first stage as CFI = 0.91, RMR = 0.015, GFI = 0.86, NNFI = 0.93 and RMSEA = 0.042. In accordance with the modification suggestion, after removal of two items from the test and connecting two items in the test with each other, the result has been found as CFI = 0.97, RMR = 0.014, GFI = 0.90, NNFI = 0.96 and RMSEA = 0.032. It can be said that fit indices generally indicate a perfect fit. The obtained fit indices have indicated perfect fit, and this is proof for validity and reliability process of the test is proven as having been conducted properly. After confirmatory factor analysis, the test has taken its final forms as a 27 items.

4.5 Suggestions

With the aim of identifying the spatial visualization abilities of students, the test mentioned in this research was developed with the addition of a mathematical context. It is predicted that the spatial abilities of students will be tested with a different approach in the studies that will be conducted for this research. Moreover, taking the tests developed for this study as a starting point, researchers are recommended to develop tests on different disciplines and on different components of spatial ability.

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