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DEVELOPMENT OF THE SPATIAL ABILITY TEST FOR MIDDLE SCHOOL STUDENTS[1]

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Abstract: The purpose of this study was to develop a test to determine spatial ability of middle school students. The participants were 704 middle school students (6th, 7th and 8th grade) who were studying at different schools from Istanbul. Item analysis, exploratory and confirmatory factor analysis, reliability analysis were used to analyse the data. Exploratory factor analysis revealed three factors: spatial visualization, spatial orientation, and spatial relations in accordance with the determined theoretical framework. Confirmatory factor analysis confirmed that these three factors constituted a model-with good fit. The Cronbach's alpha reliability coefficient for the whole of the scale was found to be .802. The findings obtained showed us that the test which was composed of twenty three items was a valid and reliable measuring instrument.

Key words: spatial ability, test development, item analysis, middle school students

1. Introduction

Innovations of our time, rapid scientific research brings new developments in the field of education. They put abstract thinking skills at the forefront. From this perspective, spatial ability has an extra important place in education (Sezen Yüksel & Bülbül, 2014). As spatial ability can be seen especially in STEM areas, instruments that are testing spatial ability start to attract attention in the literature (Turgut, 2015). Besides, spatial ability is also important in everyday life activities as well as in mathematics and geometry courses. Spatial thinking and academic performance is positively correlated with each other (Turgut & Yılmaz, 2012). Spatial ability is important not only STEM disciplines, but also in several other fields (Turgut, 2015).

Several concepts like spatial thinking, spatial perception, and spatial reasoning are used instead of spatial ability (NCTM, 2000; Olkun, 2003). It can be said that these differences come from discussing spatial ability from different perspectives. There is a great diversity about the definition of the spatial ability. The reasons of this confusion can be as follows: Different definitions of spatial ability, and presenting components in different numbers and names provided by different researchers (D'Oliveira, 2004). Spatial ability is a combination of some skills, such as imagining the objects from different perspectives, moving objects in the mind, mental rotation, visualizing 2D and 3D geometric figures (Olkun, 2003; Turgut, 2007; Hegarty & Waller, 2004). In this study, spatial ability was examined by dividing them into three components which were accepted by Lohman (1988): spatial relations, spatial orientation and spatial visualization.

Lohman (1979) used three basic factors for spatial ability. First one is *spatial relations* component and it is tested by using tests requiring rapid performance in rotating two-dimensional objects in mind (i.e. card rotation tests). Later, Lohman (1988) named this component as speeded rotation. In another definition, the concept of spatial relations is defined as the ability about rotating two or three-dimensional objects as a whole in mind and recognizing images with their rotated forms (Olkun & Altun, 2003).

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Spatial orientation is the ability about imagining how a figure is perceived from another position (Lohman, 1988) in other words there is a perspective change. In the studies carried out recently there are abilities like cognitive maps, map reading, environmental geometry, the position of an object and sense of direction in spatial orientation ability (Wolbers & Hegarty, 2010; Sarama & Clements, 2009).

According to Lohman (1988) *spatial visualization* component includes more challenging tasks. It requires an order of visual representation against more complex stimulant. Paper folding tests and mental rotation of three-dimensional objects are used to test spatial visualization (Hegarty & Waller, 2005). In another definition, spatial visualization means the ability to create images and to be able change and use them in mind (Karaman, 2000).

Lohman accepted other components that described for spatial ability by some researchers like Carroll (1993) (i.e. closure speed, perceptual speed, and visual memory) but he accepted them as a secondary component for spatial ability not as a basic component (Hegarty & Waller, 2005).

As spatial ability components can be described in numerous ways, different instruments are used to test these skills. One of the scales used for spatial relations component is Card Rotation test which was developed by Ekstrom et al. (1976). The same researchers were also developed Cube Comparisons test for the spatial relations. Besides, Group Embedded Figures Test is used for this purpose as well (Oltman et al.,1971). One of the tests which was used for determining spatial visualization is Paper Folding test which was developed by French (1963) and his friends. Another example for spatial visualization test is “Middle Grades Mathematics Project: Spatial Visualization” test. It was developed for middle school students by Winter et al. (1989) in USA. In the test, there are some questions about the image of an object from right, left, front and back view. The other tests for spatial visualization ability are Paper Folding and Surface Development tests which were developed by Ekstrom et al. (1976). One of the testing instruments used for testing spatial orientation ability is the one which was developed by Kozhevnikov and Hegarty (2001) and called as “Object Perspective/Spatial Orientation Test”. Another test used in this section is Guay’s (1976) “Purdue Spatial Visualization Test: Views”.

The purpose of this study was to develop a test which can be used for determining middle school students’ spatial ability. Through this test which was prepared in accordance with the definitions of three different components (spatial relations, spatial visualization and spatial orientation), students’ spatial ability can be evaluated generally and each component separately.

2. Method

Scale development process included the following steps: constructing test questions, consulting for expert opinions for content validity, item analysis, and exploratory factor analysis, confirmatory factor analysis and reliability analysis for construct validity.

2.1. Participants

The participants included 6th, 7th, and 8th grade middle school students (N= 704) were from three different schools in Istanbul in the present study. 154 of the participating students were 6th grade, 272 of them were 7th grade, and 278 of them were 8th grade. Exploratory and confirmatory factor analysis studies were conducted with data obtained from all participants. The test-re-test reliability analysis of the test was carried out with 60 7th grade students. Students’ gender or academic achievement status was not taken into account.

2.2. Constructing Spatial Ability Test items and content validity

At the beginning of the test development process, theoretical background of spatial ability and scales about spatial ability in the literature were reviewed. Based on Lohman (1988) three components were determined: spatial relations, spatial orientation, and spatial visualization. Test items were formed and the initial form of the scale was sent to experts to take opinions about the items.

In the first form of the test, there were twenty eight questions and seven sections. Twelve questions of the test were about spatial visualization, eight questions were about spatial orientation, and eight questions were about spatial relations component. To ensure the content validity, the initial version of the test was sent to two mathematics teachers and five mathematics teaching specialists in total seven experts. The scale was revised in accordance with the experts' opinions and it was sent back to the experts again to re-evaluate. There were nine people who evaluated the test again. They were two mathematics teachers, one testing and evaluation expert and six mathematics teaching specialists. The experts evaluated each test item according to their suitability to the theoretical framework. Based on their feedbacks, the final form of the spatial ability test was created. Consequently, in the last version of the test included twenty four questions, seven sections. The questions for spatial relations and spatial visualization ability were prepared in two sub-part and the ones for spatial orientation were prepared in three parts. There were eight questions in each spatial component. The questions for spatial orientation were in 2nd, 5th, and 7th part, the questions for spatial relations were in 1st, 4th part and the questions for spatial visualization were in 3th and 6th part of the final form of the test. Some examples from each part of the Spatial Ability Test were as follows:

There was a brief explanation in each part of the spatial ability test. In addition, a question similar to the questions was answered as an example before the questions were passed.

The example questions for the spatial relations parts of the test were as follows: In the questions prepared for the first part, there were some figures showing various objects and their rotated forms (see Figure 1). In each question, there was one figure above the line and four figures below the line. Three of the figures which were below the line were the rotated form of this figure and one was not. Students were asked to find which figure was not the rotated form of this object.

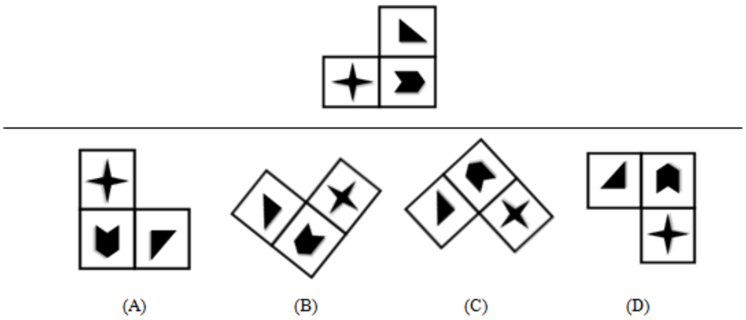


Figure 1. *An example question for the first part*

In the questions prepared for the spatial relations in fourth part of the test, there was a figure above the line and four figures below. Three figures below the line were the same as the figure above the line and they were created by rotating it from various angles and the figure in the fourth option was a different one. The students were asked to find the figure which was not the same as the figure above the line (see Figure 2).

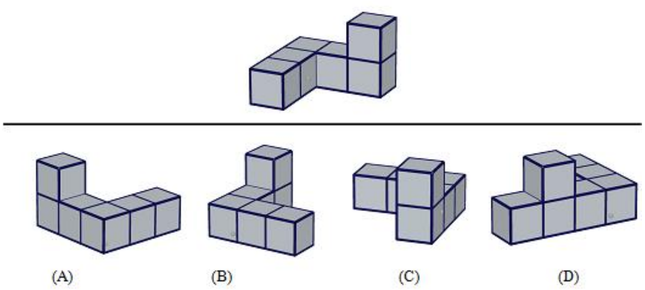


Figure 2. *An example question for the fourth part*

The example questions for the spatial orientation parts of the test were as follows: In the questions prepared for the second part, a "coordinate system" was given to determine the directions between some objects and an image which was composed of various objects was given. Students were asked to determine the place of the other two objects imaginatively by imagining that this object was in the centre of the coordinate system and place it in the coordinate system (see Figure 3).

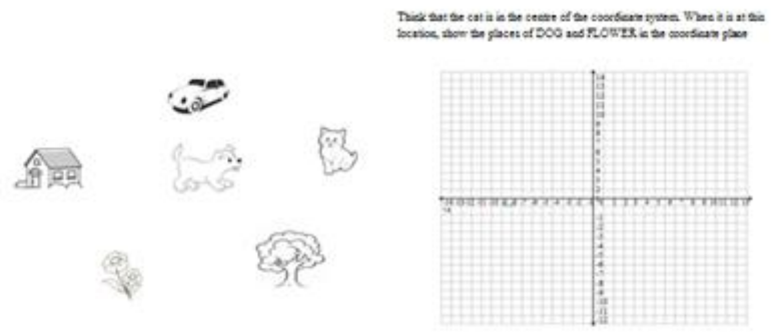


Figure 3. *An example question for the second part*

In the questions prepared for the fifth part of the final form of the test, somebody was looking at figures made from cubes. Students were asked to find out which figure was the view of the figure given below the line according to their own perspectives (see Figure 4).

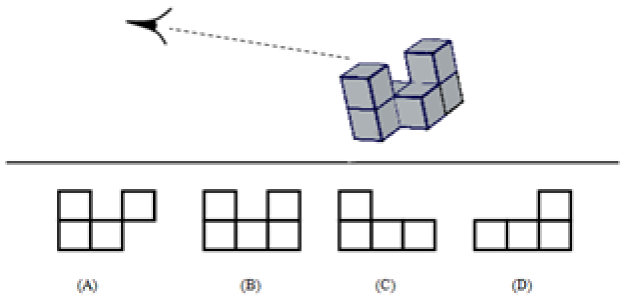


Figure 4. *An example question for the fifth part*

In the questions prepared for the seventh part of the test; front, side and upper views of a figure were given above the line and below the line the original form of the figure was given. Students were asked to find the figure by considering the view of the figure from three different sides (see Figure 5).

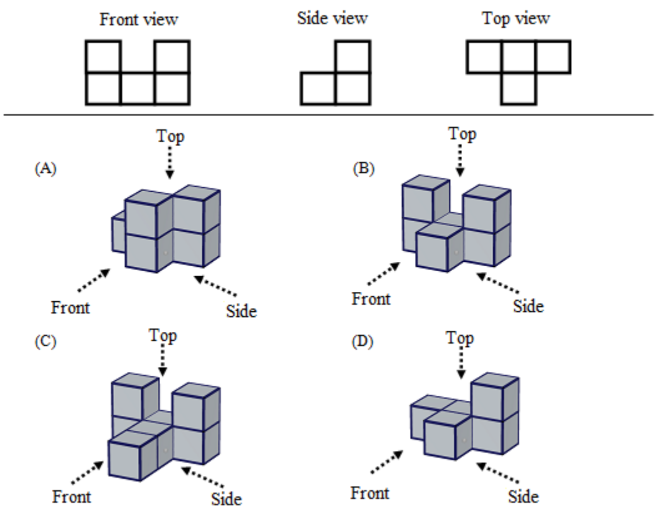


Figure 5. *An example question for the seventh part*

The questions for the spatial visualization parts of the test were as follows: In the questions prepared for the third part of the test, there was a figure above the line and below the line some figures which could be used to create that figure. Students were asked to form the figure below the line by using the figure above the line only once and without changing them (see Figure 6).

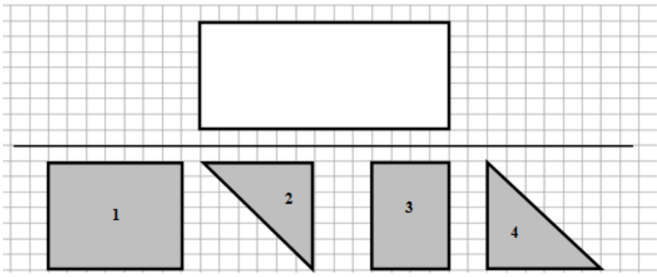


Figure 6. *An example question for the third part*

In questions prepared for the sixth part of the test, there were various objects and figures showing the development of the figures. The object could be created by folding one of the figures which was below the line. Students were asked to find out the development which formed the object that above the line (see Figure 7).

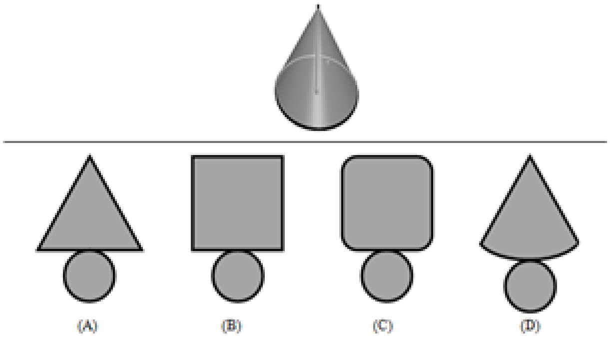


Figure 7. *An example question for the third part*

2.3. Data analysis

Obtained data was analysed with the statistical software packages. Item analysis, exploratory factor analysis, confirmatory factor analysis, and reliability analysis were used to analyse the data. In the exploratory factor analysis, how many items are included and how the relation between them is determined in a measurement tool prepared as a draft. In the confirmatory factor analysis, it is examined whether the model obtained by the exploratory factor analysis is verified or not (Sönmez & Alacapınar, 2014). Confirmatory factor analysis was carried out with data from 704 students in which exploratory factor analysis was performed. Cronbach's alpha reliability coefficient and test-retest reliability were used for the reliability analysis.

3. Results

The findings of item analysis, exploratory factor analysis, confirmatory factor analysis, and reliability analysis were presented in this part.

3.1. Item analysis

According to the item analysis results, the lowest difficulty index value was obtained as 0.08 and the highest value as 0.42. The item difficulty index values of other questions ranged between 0.14 and 0.40. According to this, it can be said that this test is a difficult test. Considering the item selectivity index values, it was seen that the lowest value was -0.01 and the highest value was 0.65. The other questions' selectivity index values differed between 0.38 and 0.64. Consequently, this test was a very good one in terms of selectivity. The question 4.1 was removed from the test as its selectivity value (-0.01) was low. Other results belonging to item analysis were as given Table 1.

Table 1. Item analysis results of Spatial Ability Test

Number of Items	24
Number of Participants	704
Average	11.9
Standard Deviation	4.75
Kurtosis	-0.301
Skewness	0.296
Average Item Difficulty	0.11
Average Item Selectivity	0.24

3.2. Exploratory factor analysis of Spatial Ability Test

For construct validity of the spatial ability test, exploratory factor analysis with principal components method was conducted. In order to determine whether the data was suitable to the factor analysis, Kaiser-Mayer-Olkin (KMO) and Bartlett's Spherecity Test values were calculated. For this study, KMO value was found as 0.812 and Bartlett's Spherecity Test results were significant (X^2=2637.853, sd=253, p<0.01). According to Büyüköztürk (2012) test results show that data are suitable for the factor analysis.

Exploratory factor analysis was performed with 23 items, and 7 factors whose eigenvalue was higher than 1 was obtained. Additionally, the Scree Plot graphic (see Figure 8) was examined to determine the number of factors of the scale.

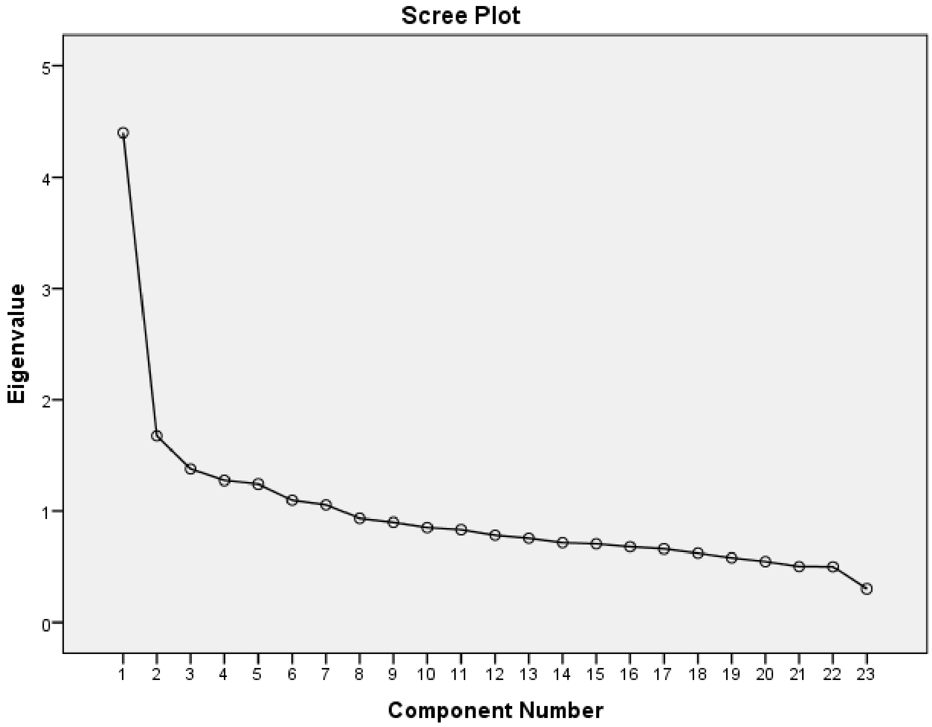


Figure 8. *The Scree Plot graphic of Spatial Ability Test*

As seen in Figure 8, the Scree Plot graphic suggested that five factors existed. The distances between factors after the seventh point were very similar. The factor loading of each item was analysed by utilizing Promax rotation method. The findings obtained as a result of exploratory factor analysis were given in Table 2.

Table 2. Sub-factors and factor loadings obtained from the exploratory factor analysis

Item No	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
3.1	.777						
3.2	.790						
3.3	.607						
3.4	.611						
6.1		.525					
6.2		.749					
6.3		.690					
6.4		.726					
4.1			.606				
4.2			.727				
4.4			.684				
5.1				.763			
5.2				.710			
5.3				.559			
2.1					.881		
2.2					.890		
1.1						.648	
1.2						.808	
1.3						.346	
1.4						.540	
7.1							.591
7.2							.563
7.3							.736
Eigen values	4.399	1.675	1.379	1.275	1.242	1.098	1.056
Total Variance Explained: 52.714 %	19.126 %	7.284 %	5.995 %	5.543%	5.402 %	4.775 %	4.590 %

As seen in Table 2, these seven factors explained 52.714 % of the total variance. The first factor explained 19.126 % of the total variance and contained four items. The second factor, which explained 7.824 % of the total variance, included four items. The third factor explained 5.995 % of the total variance and contained three items. The fourth factor, which explained 5.343 % of the total variance, included three items. The fifth factor explained 5.403 % of the total variance and contained two items. The sixth factor, which explained 4.775 % of the total variance, included four items. The seventh factor explained 4.590 % of the total variance and contained three items. The factor loadings of the whole scale items varied between .346 and .890. Since factor loads of all items were over .30 (Büyüköztürk, 2012) and the scale's total variance was over 52 % (Henson & Roberts, 2006) they reached acceptable levels.

According to exploratory factor analysis results, the first factor matched with the 3^{th} part, the second factor matched with the 6^{th} part, the third factor matched with the 4^{th} part, the fourth factor matched with the 5^{th} part, the fifth factor matched with the 2^{nd} part, the sixth factor matched with the 1^{st} part, the seventh factor matched with the 7^{th} part of the final form of the Spatial Ability Test. When it was examined according to determined spatial components, results were as given in Table 3.

Table 3. Factor numbers according to spatial ability components

Spatial Ability Component	Part number in the final form of the test	Factor number obtained from exploratory factor analysis
Spatial Orientation	2	5
	5	4
	7	7
Spatial Relations	1	6
	4	3
Spatial Visualization	3	1
	6	2

5th, 4th, and 7th factors were related to spatial orientation ability, 6thand 3th factors were related to spatial relations ability, 1st and 2nd factors were related to spatial visualization ability.

3.3. Confirmatory factor analysis of the Spatial Ability Test

After performing exploratory factor analysis of the spatial ability test, confirmatory factor analysis was conducted to determine whether the obtained factors constituted a good model. The criteria used for evaluating the fit indices are determined by various researchers. When the X^2/sd rate which is used for specifying the suitability between model and data is 3 or smaller 3, it shows perfect fit, when it is between 3 and 5, it shows acceptable fit (Sümer, 2000). For IFI, RFI indices, the values between .90 and .95 show acceptable fit and the ones over .95 shows perfect fit (Marcholudis & Schumacher, 2001). For AGFI and GFI index the values between .85 and .90 express an acceptable fit and the ones over, .90 mean perfect fit (Marcholudis & Schumacher, 2001). For RMSEA and RMR indices the values between .00 and .05 show acceptable fit (Şimşek, 2007; Meydan & Şeşen, 2011). For PGFI and PNFI indices the values between.50 and .95 shows acceptable fit (Meyers, Gamst & Guarino, 2006) values over .95 and 1.00 mean perfect fit (Meydan & Şeşen, 2011). Besides, having PGFI value close to 1.00 shows that the model is simple and modest (Sümer, 2000). For CFI index the values between .90 and .95 presents acceptable fit and the values over .95 perfect fit (Hu & Bentler, 1999, Marcholudis & Schumacher, 2001). For SRMR index the values between .00 and .05 show perfect fit and the values between .05 and .10 present acceptable fit (Kline, 2011).

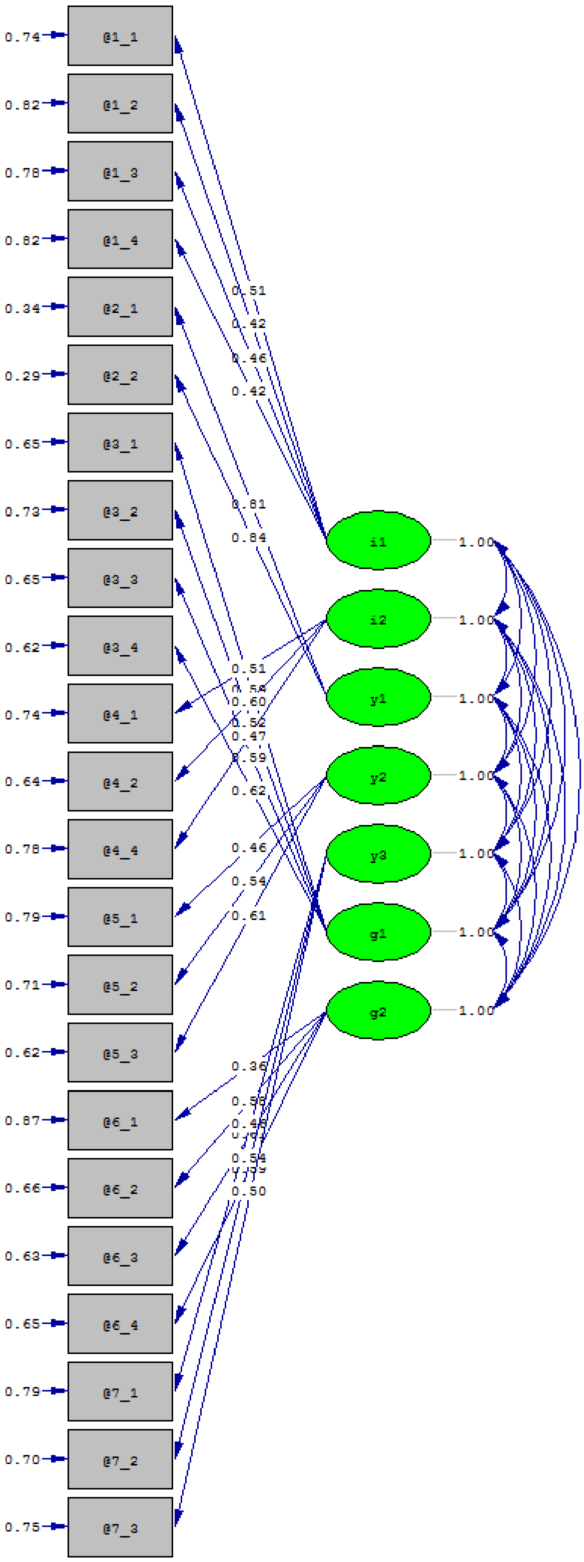
Considering the criteria stated above, the goodness of fit indices of the model were found at an acceptable level (X^2=293.82, df=209, X^2/df= 1.40, AGFI=0.95; CFI=0.97, GFI=0.96, NNFI=0.96, IFI=0.97, RMSEA=0.024, RMR=0.0074, SRMR=0.032, PGFI=0.73, PNFI=0.74). The results of the first order confirmatory factor analysis of the scale were given in Table 3.

Table 4. The first order confirmatory factor analysis results

Analysed Fit Index	Obtained Fit Index	Result
X^2/df	1.40	Perfect Fit
AGFI	0.95	Perfect Fit
CFI	0.97	Perfect Fit
GFI	0.96	Perfect Fit
NNFI	0.96	Perfect Fit
IFI	0.97	Perfect Fit
RMSEA	0.024	Perfect Fit
RMR	0.0074	Perfect Fit
SRMR	0.032	Perfect Fit
PGFI	0.73	Acceptable Fit
PNFI	0.74	Acceptable Fit

The model and factor loadings obtained from the first order confirmatory factor analysis of the spatial ability test were given in Figure 9.

When Figure 9 was examined, the factor loadings of the scale differed between .36 and .84 and the item factor loading values of the scale were at the desired level. As all the fit index values of the model were at the sufficient level, the first level confirmatory factor analysis of the tested model was approved.



Chi-Square=293.82, df=209, P-value=0.00010, RMSEA=0.024

Figure 9. *The first level confirmatory factor analysis results and standardized solutions*

The second level confirmatory factor analysis must be carried out with multiple-factor scales (Seçer, 2015). The second level factor analysis results of the spatial ability test were given in Table 5.

Table 5. The second order confirmatory factor analysis results

Analyzed Fit Index	Obtained Fit Index	Result
X^2/df	1.45	Perfect Fit
AGFI	0.95	Perfect Fit
CFI	0.96	Perfect Fit
GFI	0.96	Perfect Fit
NNFI	0.95	Perfect Fit
IFI	0.96	Perfect Fit
RMSEA	0.025	Perfect Fit
RMR	0.0080	Perfect Fit
SRMR	0.035	Perfect Fit
PGFI	0.77	Acceptable Fit

The proposed model fit indices obtained from second order confirmatory factor analysis were as follows: X^2/df= 1.45, AGFI=0.95; CFI=0.96, GFI=0.96, NNFI=0.95, IFI=0.96, RMSEA=0.025, RMR=0.0080, SRMR=0.035, PGFI=0.77, PNFI=0.77. All the fit indices were acceptable and significant (X^2=319.08, df=220, $p<0.01$). The second order confirmatory factor analysis confirmed that the model had perfect fit.

Model and item load values displaying the second level confirmatory factor analysis of the spatial ability test were given in Figure 10.

There were seven first order factors and three second order factors in the second model. Path coefficients (standard regression coefficients) for the first order factors varied between .36 and .84. In addition, the second order factors item load values varied between .55 and .80.

3.4. Reliability studies

For the reliability of the spatial ability test, Cronbach's alpha and test-retest reliability values were examined. When the responses provided for the test were evaluated as 0-1, Cronbach's alpha coefficients are known to give the same result with KR-20 (Cronbach, 1951). The Cronbach's alpha internal consistency coefficient of the developed spatial ability test was found as .802. In general scales which have reliability coefficients over .70 are accepted as reliable (Fraenkel, Wallend & Hyun, 2012) this scale is adequately reliable. Besides, for determining test-retest reliability, the scale was given to 60 7th grade students. Test re-test correlation was and .561 value and significant ($p<0.01$). These results confirm that spatial ability test is a reliable testing instrument for testing middle school students' spatial ability.

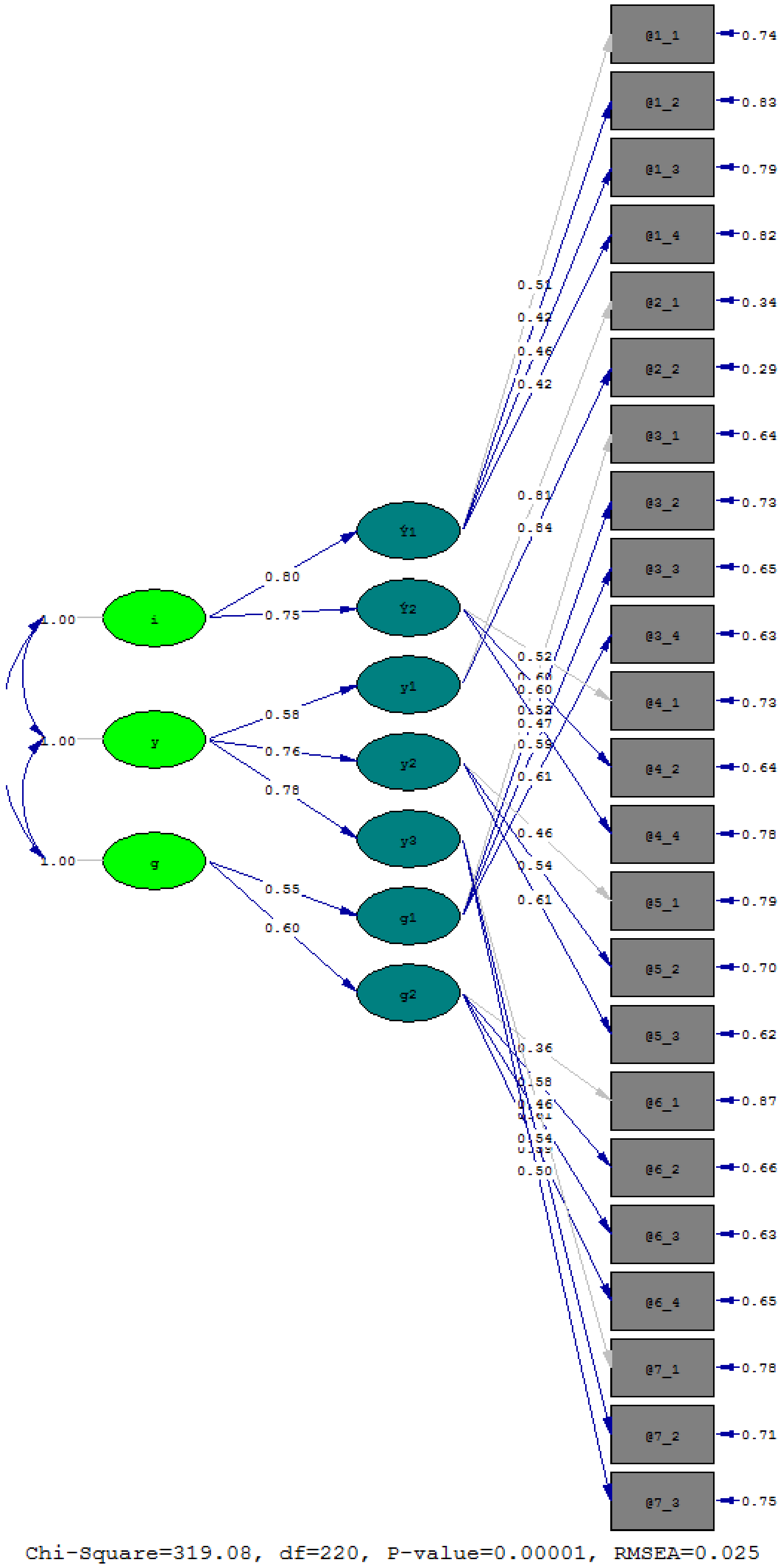


Figure 10. *The second level of confirmatory factor analysis results and standardized solutions*

4. Discussion and conclusion

The purpose of this study is to develop a valid and reliable testing instrument which can be used for middle school 6th, 7th and 8th grade students. In the constructing items process of spatial ability test, three components of spatial ability which were determined by Lohman (1988) were considered. Questions in seven categories analysing spatial correlations, spatial orientation and spatial visualisation were sent to experts. The opinions of the experts were evaluated one by one and the content and face validity of the scale was ensured.

As result of the item analysis of the Spatial Ability Test, one item was removed from the scale as its item discrimination was low. For construct validity, exploratory and confirmatory factor analyses were made for the remaining items. At the end of the exploratory factor analysis, it was determined that the testing instrument has a seven-factor structure explaining 52.714 % of the testing instrument. This value fulfils the condition which was stated by Henson and Roberts (2006) as multiple-structured scales' total variance should be 52 and over. The factors obtained with exploratory factor analysis and categories specified while preparing the items of the scale by considering the theoretical framework match with each other. It was seen that factor load values of the items in the scale were over the specified criteria (Büyüköztürk, 2012) 0.30. After exploratory factor analysis, confirmatory factor analysis was carried out to analyse the suitability of the items to the specified model. As it is necessary to carry out the second level factor analysis in multiple-factor scale together with the first level confirmatory factor analysis (Seçer, 2015) confirmatory factor analysis of the spatial skills test at each level were conducted. The results of the first level confirmatory factor analysis showed that fit indices regarding seven-factor structure are sufficient. The values like AGFI=0.95, GFI=0.96, NNFI=0.96, CFI=0.97, IFI=0.97, RMSEA=0.024 proves that data have a perfect fit with the given model. Path diagram displaying three different components of the spatial ability specified for this study and involving seven factors were created with the second level confirmatory factor analysis. Also, the values obtained as a result of the second level confirmatory factor analysis show that the suitability of the model is perfect (AGFI=0.95, GFI=0.96, NNFI=0.95, CFI=0.96, IFI=0.96, RMSEA=0.025). It can be said under the light of this information that construct validity of the spatial skills test was ensured.

The results of the reliability analysis of the spatial skills test showed that the scale is reliable. As Cronbach's alpha reliability coefficient is.802, the scale is adequately reliable (Fraenkel, Wallend & Hyun, 2012). Besides, its correlations is statistically significant ($p<0.01$).

The findings obtained as a result of this study displayed that spatial skills test whose final version includes 23 items can be used as a reliable and valid testing instrument. The purpose of this study is to bring a scale aiming to test middle school students' spatial skills especially to the teaching mathematics field and other branches in education.

Different testing instruments were developed by making different definitions about spatial ability and its components. A spatial ability test for middle school students involving spatial relations, spatial orientation and spatial visualization sub components have not been seen so far. Thanks to this scale we will have opportunities to evaluate students' spatial ability both generally and separately for the components. From this perspective, the scale is important as it fills a gap in the literature. The scale is designed especially for middle school students but it can also be used for the first two years of the high school level. As tests are having more importance in STEM fields that spatial skills are especially important (Turgut, 2015) it is thought that this scale will useful and necessary for the next terms. Since research data was collected by using middle school students, it was concluded that this scale is suitable for this age group. The suitability of the scale for upper or lower levels depends on the results of the study that will be carried out in the future.

It is thought that the spatial skills test developed in this study will contribute to the other studies in the future. The study can be expanded by adding different components to the spatial ability components used in this study.

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