Spatial Ability Test for Upper-Elementary School Student: Confirmatory Factor and Normative Data Analysis

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Abstract

The purpose of this study was to develop spatial ability test for elementary school children, to verify the construct validity, and to derive norms of the test. The sample consisted of 438 upper-elementary school students of Piboonbumpen Demonstration School, Burapha University. Students were randomly selected by multistage sampling. Descriptive statistics were obtained by means of SPSS. The construct validity was verified by means of a second-order confirmatory factor analysis using Mplus. The research finding the spatial ability test consisted of 3 components such as spatial visualization, spatial orientation, and spatial relations. The Kuder Richardson 20 Coefficient of reliability (KR-20) of the test is .82. The test has strong construct validity in view of the fit indexes RMSEA = .02, CFI = .98, TLI = .98 resulting from confirmatory factor analysis with categorical factor indicators. The norms for spatial ability test for elementary school children were constructed as follows: a student with a score range at 12 or lower was indicative of a low level of spatial ability, a score range from 13 to 20 indicated a moderate of spatial ability, and a score range at 21 or higher was deemed to have a high level of spatial ability.

Keywords: spatial ability, spatial visualization, spatial orientation, and spatial relations

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Introduction

The ability to imagine the travelling in a vehicle from one point to another, or to visualize the image of object in different perspective in your mind is known as spatial ability. This ability is defined as a combination of skills, such as moving objects mentally, integrating and disintegrating the objects in the mind or visualizing the objects from a different perspective (Hegarty & Waller, 2004; Linn & Petersen, 1985). The development of spatial ability is considered required; these skills may, therefore, affect students' future career choices (Uttal & Cohen, 2012). Kell, Lubinski, Benbow, and Steiger (2013) confirmed that early spatial ability predicts creativity, innovation and performance in Science, Technology, Engineering and Mathematics (STEM) fields. Kerkman, Wise, and Harwood (2000) also noted that this ability is clearly important for a number of high-paying professional careers such as dentistry, medicine, architecture, engineering, navigation, and others.

The spatial ability is important not only in STEM fields (Uttal & Cohen, 2012), but also in various other disciplines, such as geography education (Montello, Lovelace, Golledge, & Self, 1999), map learning (Pazzaglia & Moe, 2013), sport sciences (Pietsch & Jansen, 2012a, 2012b) and medicine (Clem, Donaldson, Curs, Anderson, & Hdeib, 2013). Similarly, other studies have found spatial ability to be positively correlated with academic thinking and academic performance (Turgut & Yilmaz, 2012). Additionally, spatial ability is a significant component of intellectual ability (Gardner, 2011).

Although there is general agreement about the importance of spatial ability and that there is not just one skill, researchers in cognitive science have endeavored to characterize the skills that comprise spatial thinking and define the categories of spatial skills. A number of attempts have been made to characterize the dimensions of spatial ability by identifying commonalities in the cognitive mechanisms (Maccoby & Jacklin, 1974), identifying clusters in skill using meta-analyses and factor analyses (Ekstrom, French, Harman, & Derman, 1976; Linn & Petersen, 1985), using computational modeling (Smith, Pellegrino, & Golledge, 1982), and using neuroscience methods to identify candidate biological substrates associated with different types of spatial ability (Vogel, Bowers, & Vogel, 2003).

Spatial ability has had many definitions in the literature. Tartre (1990) considers spatial ability as the mental skills concerned with understanding, manipulating, reorganizing, or interpreting relationships visually, while Lohman (1996) define it as the ability to generate, retain, retrieve, and transform well-structured visual images. Lohman (1988) proposes a three-factor model for spatial ability, covering spatial visualization, spatial orientation, and spatial relations. Accordingly, spatial visualization is the ability to comprehend imaginary movements in a three-dimensional space or the ability to manipulate objects in imagination, spatial orientation is defined as a measure of one's ability to remain unconfused by the changes in the orientation of visual stimuli that require only a mental rotation of configuration, and spatial relation is defined by the speed in manipulating simple visual patterns such as mental rotations and describes the ability to rotate mentally a spatial object quickly and correctly.

McGee (1979) felt that spatial visualization tasks all involve the ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object. Kersh and Cook (1979) also suggested that tests of spatial visualization involve either the rotation or transformation of a mental object. Spatial visualization is distinguished from spatial orientation tasks by identifying what is to be moved; if the task suggests that all or part of a representation be mentally moved or altered, it is considered a spatial visualization task (McGee, 1979). By this definition, Form Boards and Card Rotations and the Space Relations portion of the DAT are examples of tests of this class of spatial skills. Spatial orientation tasks do not require mentally moving an object. Only the perceptual perspective of the person viewing the object is changed or moved. McGee (1979) stated that spatial orientation tasks involve the comprehension of the arrangement of elements within a visual stimulus pattern and the aptitude to remain unconfused by the changing orientation in which a spatial configuration may be presented. This means that spatial orientation items suggest that the person understand a representation or a change between two representations. The spatial orientation tasks involves ones that require that the subject mentally readjust her or his perspective to become consistent with a representation of an object presented visually. Spatial orientation tasks could involve organizing, recognizing, making sense out of a visual representation, reseeing it or seeing it from a different angle, but not mentally moving the object. By this definition, the Gestalt Completion Test, the Hidden Figures Test, the Rod and Frame Test, and other hidden object puzzles are examples of tests of spatial orientation skill. Lohman (1988) believes that spatial relations factor is defined by the tests in which subjects are required to determine whether a given stimulus is a rotated version of a two dimensional target (i.e., game card) or is a rotated and reflected version of it. A quick answer is expected from the examinees when taking those kinds of tests.

Purpose of the study

The present study aimed firstly to develop spatial ability test for elementary school children. The second research aim was to verify the construct validity of the test. The last research aim was to derive norms for the test.

Conceptual Framework

Based on concept of Pittalis and Christou (2010) and Lohman (1988), spatial ability has a theoretical construct defined by three second-order spatial ability factor, namely spatial visualization, spatial orientation, and spatial relations, as in figure 1.

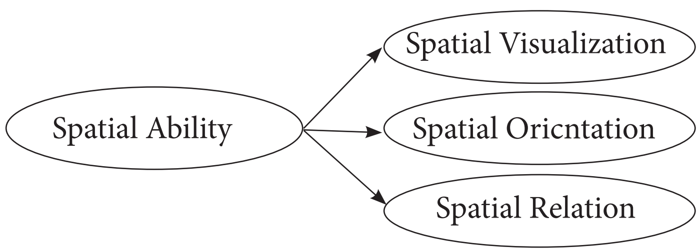


Figure 1: Second-order factor of spatial ability

Scope of the study

This study was only conducted with upper-elementary school student, grade 4 to grade 6, with the age range of 9 to 12. Variables in the study consist of 4 latent variables and 30 observed ones. One latent variable is spatial ability, in the second-order of model, and the others three-latent variables are spatial visualization, spatial orientation, and spatial relations, in the first-order of model or namely spatial ability's component. The thirty-observed variable is item indicated each components and divided ten items per component.

Methodology

Participants

The participants were 438 upper-elementary school students of Piboonbumpen Demonstration School, Burapha University. Students were randomly selected by multistage sampling. Overall, the participants consisted of 217 females (49.50%) and 220 males (50.50%) and with the age range from 9 to 12 year-old. In the sampling, the rates of the 4th, 5th, and 6th grade prospective students were 36.07% (n=158), 27.40% (n=120), and 36.53% (n=160).

Instruments

Spatial ability test is visual test with four choices (one correct choice) developed in Thai version by using concept of McGee (1979) and Newton (2009). The test has three parts (spatial visualization, spatial orientation, and spatial relations) with 10 items each. When the participant take correct answer, he will get 1 point. Total score is sum point of correct answer.

In stage of content validity and measurement model, four items of spatial visualization and one item of spatial relations were removed from the test because the item objective congruence average (IOC) is less than .5 (Fornell, 1981) or item's loading is less than .2 (Hair Jr., Black, Babin, & Anderson, 2010). Spatial visualization part, therefore, consist of 6 items and has score range from 0 to 6 points. Spatial orientation part consist of 10 items and has score range from 0 to 10 points. And spatial relations part consist of 9 items and has score range from 0 to 9 points. Overall score of spatial ability has range from 0 to 25 points. The Kuder Richardson (KR-20) method was used to access test reliability. The KR-20 coefficient of each components – spatial visualization, spatial orientation, and spatial relations, respectively are .51, .75, and .64. And the overall KR-20 is .82. Values of KR-20 generally range from 0.0 to 1.0, with higher values representing a more internally consistent test. A rule-of-thumb commonly applied in practice is that 0.5 is an acceptable value for tests less than 30 items (Thompson, 2010). It means, therefore, the items of each components confirm the consistency, repeatability, or homogeneity of measurement given a set of item responses.

Data collections

Researchers collected data by themselves by requesting to school director and dating with homeroom teacher to use students' free time for collecting data. Data collection was conducted from 1 to 15 September 2014

Data analysis

Descriptive statistics such as number and percent of participant were firstly conducted by using SPSS. After, the construct validity was verified by means of first-order (measurement model) and second-order confirmatory factor analysis by using Mplus. The percentile range and the standard nine-point score (stanine) was finally conducted by Excel.

Research Result

Confirmatory factor analysis

In order to respond to the research objective, to verify the construct validity of the spatial ability test for elementary school children, two step of data analysis were conducted in this research. Measurement model of each latent variable were, first step, used to confirm developed items indicate one's trait by using first-order confirmatory data analysis with categorical variables. The result of fitness indices was accepted that the model exhibited a sufficient fitness. The standardized factors loading of six-item spatial visualization are in the range from .32 to .83. The standardized one of ten-item spatial orientation are in the range from .44 to .87. And the range-standardized factors loading of nine items indicated spatial relations are in .32 to .63. The standardized factors loading are over .50 (Hair et al., 2010), indicating a completely satisfied model of measurement systems. After verifying the measurement model for indicating each component's trait, the second-order confirmatory factor analysis with categorical data was conducted and the detail shows in table 1.

Table 1: The second-order confirmatory factor analysis with categorical data of spatial ability test

Component / Indicator	Standard Loading	Standard Error	R^2
The first-order confirmatory factor analysis			
Spatial visualization (SV)			
Item 1	.49**	.07	.24
Item 2	.58**	.08	.33
Item 3	.63**	.10	.39
Item 4	.61**	.08	.38
Item 5	.34**	.08	.11
Item 6	.71**	.07	.50
Spatial orientation (SO)			
Item 1	.58**	.07	.33
Item 2	.40**	.07	.16
Item 3	.64**	.06	.41
Item 4	.70**	.05	.48
Item 5	.53**	.09	.28
Item 6	.72**	.06	.53
Item 7	.72**	.05	.52
Item 8	.73**	.06	.54
Item 9	.90**	.04	.81
Item 10	.65**	.06	.43

Table 1: The second-order confirmatory factor analysis with categorical data of spatial ability test

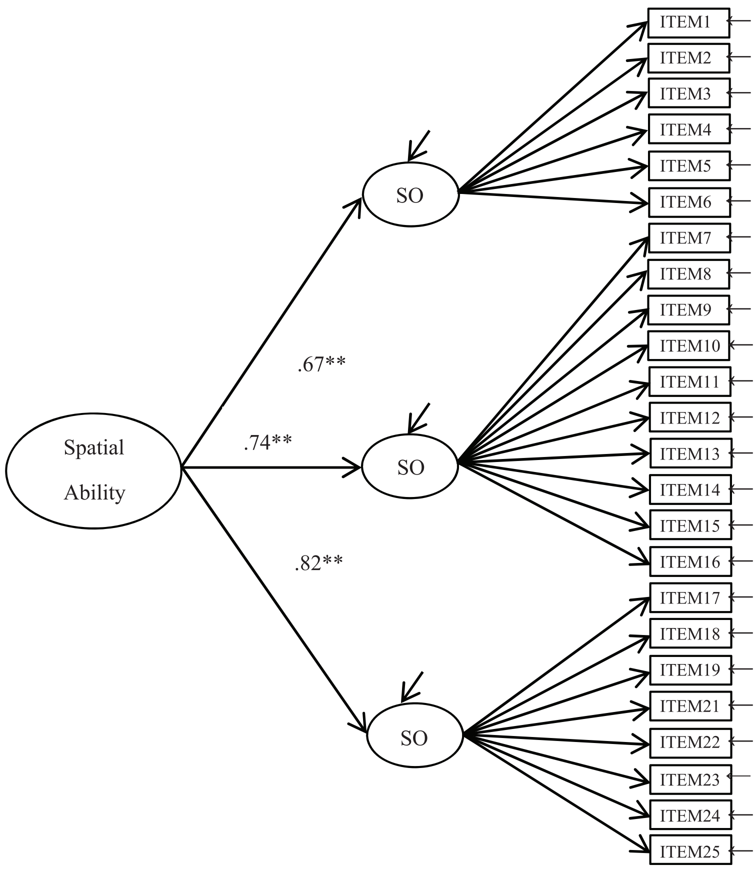
Component / Indicator	Standard Loading	Standard Error	R^2
The first-order confirmatory factor analysis			
Spatial relations (SR)			
Item 1	.44**	.07	.20
Item 2	.71**	.06	.51
Item 3	.50**	.06	.25
Item 4	.63**	.07	.39
Item 5	.51**	.07	.26
Item 6	.48**	.06	.23
Item 7	.42**	.07	.18
Item 8	.45**	.07	.20
Item 9	.51**	.07	.26
The second-order confirmatory factor analysis			
Spatial visualization (SV)	.67**	.07	.45
Spatial orientation (SO)	.74**	.06	.55
Spatial relations (SR)	.82**	.06	.67

**p < .01, R2 predicted coefficient

The second-order confirmatory factor analysis with categorical variables model fits with the empirical data well by means of the fit indexes: chi-square (χ^2 = 299.88) , relative chi-square (χ^2 df =1.14) , root mean square error of approximation (RMSEA = .02), comparative fit index (CFI = .98), and Tucker-Lewis index (TLI = .98), as in figure 2. The result confirms the test has strong construct validity. The spatial ability makes up three components and 25 indexes. In view of important level of three components, spatial relation is main component inferior to spatial orientation and spatial visualization respectively. Each component (Spatial visualization, spatial orientation, and spatial relation) can indicate spatial ability trait with percentage of 45, 55, and 67 respectively. The component of spatial visualization is significantly indicated by six items with standard loading range from .34 to .71. As to spatial orientation is indicated by ten items with standard loading range from .40 to .90. And the last nine items with standard loading range from .42 to .71 are the indicators of spatial relation, as detail in table 1.

Normative analysis

The data from 438-upper elementary school student show that the maximum score of spatial ability is 25 points and the minimum score is 4 points. The corresponding value of stanine and percentile score followed the concept of Wiersma and Jurs (1990) show in table 2. The norm of spatial ability test divided in three level such as (1) point of 0 to 12 define that student has spatial ability in low standard, (2) point of 13 to 20 define that student has spatial ability in normal standard, and (3) point of 21 to 25 define that student has spatial ability in higher standard, as data in table 3



χ^2 = 299.88 (p = .054), df =262, χ^2 df = 1.14, RMSEA = 0.2, CFI = .98, TLI = .98

Figure 2: Entire second-order factor of spatial ability model

Table 2: Stanine, percentile, and spatial ability score

Stanine	Percentile	Spatial ability score
3	23	12
7	77	20

Table 3: Norm of spatial ability test

Score range	spatial ability level
0-12	Lower Standard
13-20	Normal Standard
21-25	Higher Standard

Discussion

The purpose of the study was to verify the reliability and the validity of the spatial ability test for upper elementary school student. Several analyses were performed to examine the effectiveness of the test. First, the reliability of the test was conducted by the KR-20 coefficients. The KR-20 coefficient of the test was 0.82. This value is consistent with previous research regarding KR-20 reliability (Branoff, 2000). In addition to examining the reliability of the test, construct validity test needed to be evaluated by second-order confirmatory factor analysis with categorical data. The 2nd CFA showed that model well fits with the empirical data. It confirms that this test has a strong construct validity by the model of Pittalis and Christou (2010) and Lohman (1988). For the normative data, the score of 12 and 20 are the cutting point between lower, normal, higher level of spatial ability responsively. Based on the statistical analyses, it appears that the spatial ability test, in conclusion, is as good as a measurement of spatial ability for upper elementary school student.

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