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MEASUREMENT OF GEOSPATIAL THINKING ABILITIES AND THE FACTORS AFFECTING THEM

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Abstract Since the publication of the National Research Council's report entitled "Learning to Think Spatially" in 2006, spatial thinking has been attracting attention in the fields of geographic information science and geography education. Recently, several tests for measuring spatial thinking abilities in geographical contexts have been developed. Nevertheless, the reliability of these tests and the relationship between the test questions and the components of geospatial thinking are not clear. In addition, few attempts have been made to investigate the effect of various factors, including behaviors and interests in daily life, on test scores. This study aims to improve the geospatial thinking ability test and examine the various factors affecting test scores. The test used in this study is a revision of the Spatial Thinking Ability Test developed by Lee and Bednarz (2012). Six question items were selected by considering the independence and representativeness of the components of the geospatial abilities; anonymous materials were used to distinguish between the respondents' geospatial skills and their prior knowledge. The results obtained from a sample of 90 university students showed a low correlation between the scores for the six question items. The scores for three question items (spatial patterns, spatial correlation, and landscape visualization) were closely related to the students' interest in geography and maps, as well as their sense of direction. In particular, their experience and expertise in geography at school was evident in the specific components of geospatial thinking abilities.

Key words: spatial thinking, spatial abilities, geographic information, geography education

1. Introduction

Since the publication of the National Research Council's report entitled "Learning to Think Spatially" in 2006 (NRC 2006), spatial thinking has been attracting attention in the fields of geographic information science and geography education. However, no clear consensus exists concerning the spatial thinking component and a method for measuring it. Recently, several tests for measuring spatial thinking abilities in geographical contexts have been developed. Lee and Bednarz (2009) used a spatial-skills test to examine the effects of geographic information system (GIS) learning on the spatial thinking abilities of college students. The test, which included seven types of question items, was administered to students before and after GIS learning. Nevertheless, the researchers only compared total test scores, and did not pay attention to variation among the test items.

Lee and Bednarz (2012) further refined the spatial-skill test to develop the Spatial Thinking Abilities Test (STAT) in conjunction with the Teacher's Guide to Modern Geography (TGMG) project of the Association of American Geographers (AAG). The STAT included sixteen multiple-choice questions consisting of eight different types of questions (AAG 2006) based on the notion that spatial thinking skills are composed of several elements. Test results from 352 university students were analyzed with factor analysis to obtain six factors; however, correspondence between the test item types and the six factors was not evident. Huynh and Sharpe (2013) also developed a test consisting of thirty items to evaluate geospatial thinking. The test was administered to 104 university students and 11 factors were obtained from factor analysis of the test scores. However, they analyzed only six factors and did not provide detailed information for each test item.

The reliability of the abovementioned tests and the relationship between their questions and the components of geospatial thinking are not clear. Moreover, few attempts have been made to investigate the effect of various factors, including behaviors and interests in daily life, on test scores. This study aims to improve the geospatial thinking ability test and examine the various factors affecting test scores.

2. Methodology and Data

Revision of the STAT

Due to some shortcomings in the STAT, the present study revised Lee and Bednarz's (2012) test to specifically address the issues discussed below.

Selection of question items: To clarify the relationship between question types and question items, six items were selected by considering the independence and representativeness of the components of the geospatial abilities based on Lee and Bednarz's factor analysis results.

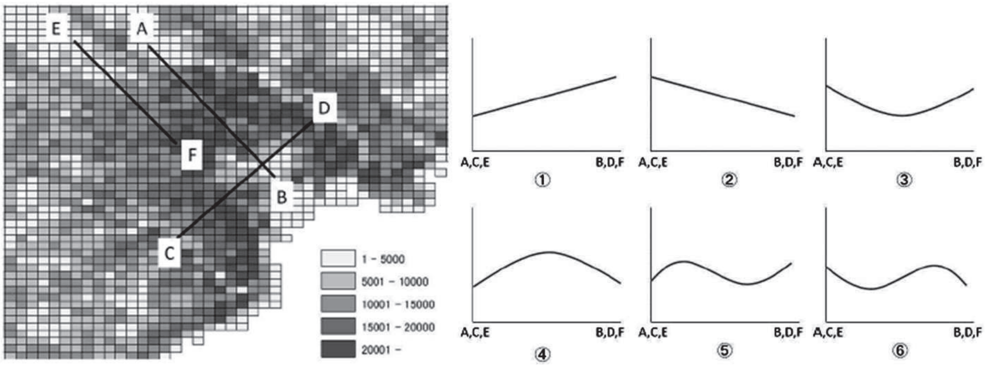
Separation of knowledge and skills: As noted by Ishikawa (2013), a distinction between conceptual knowledge and reasoning in geospatial thinking must be made. However, these two components are mixed in the STAT. Hence, anonymous materials were used to distinguish between respondents' geospatial skills and their prior knowledge.

Quantitative evaluation: The STAT's multiple-choice questions yield binary data that cannot be easily quantified. To overcome this problem, three questions for each test item were used to measure spatial thinking abilities.

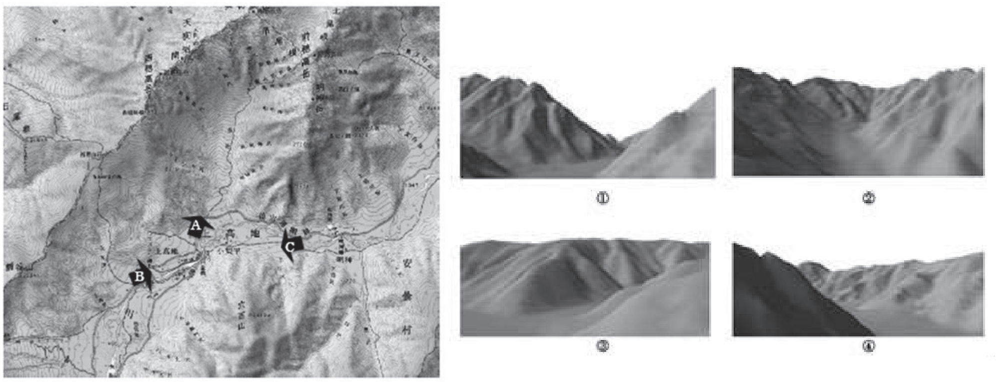
Hereafter, the present study's Japanese adaptation of Lee and Bednarz's test will be referred to as the "STAT-J." Two sample test questions with their accompanying illustrations are provided in Fig. 1. An overview of each question and its intended function is provided below.

Q1. Wayfinding: This question prompts students to visually navigate road maps using verbal information to evaluate their sense of orientation and direction. This corresponds with the first and second AAG questions.

Q2. Map pattern profile: Students must recognize map patterns and represent them in a graphic form to assess their ability to discern spatial patterns. This corresponds with the third AAG question.



Q2. The above map shows distribution of a statistical indicator. If you draw a graph showing the profiles between two points (A-B, C-D, and E-F), choose a graph suitable for each pair of points from upper-right figures.



Q5. If you look at the area below in the direction arrow (A, B and C), which is terrain view (①-④) most closely represents what you see?

Fig. 1 Examples of questions of STAT-J

Q3. Finding the best location: Learners were asked to select an ideal location for a fictitious facility based on multiple pieces of spatial information. This corresponds with the fourth AAG question.

Q4. Correlating spatial distributions: Students must identify spatial correlations between sets of maps to evaluate their ability to comprehend spatial association. This corresponds with the sixth AAG question.

Q5. Visualization: Test takers were asked to mentally visualize a 3-D image based on 2-D information to assess their ability to transform perception, representation, and images from one dimension to another. This corresponds with the eighth AAG question.

Q6. Overlaying maps: Learners must visually verify a map overlay process based on a Boolean operation to evaluate their ability to overlay and dissolve maps. This corresponds with the ninth AAG question.

Self-evaluation test

Several types of tests have been used to measure spatial thinking abilities (Lee and Bednarz 2012). These include psychometric tests, such as Ekstrom et al.'s (1976) Kit of Factor-Referenced Cognitive Tests; self-report questionnaires, such as Hegarty et al.'s (2002) self-report measure of environmental spatial ability and Takeuchi's (1992) sense of direction questionnaire form (SDQ-S); and tests of specific aspects of spatial thinking skills, such as the STAT.

Among these tests, self-report questionnaires are useful for assessing spatial skills in both small- and large-scale environments, as well as spatial behavior in everyday life. Hence, the author developed a self-evaluation test (hereafter, "SESS") to measure spatial skills, which was used in this study to examine the STAT-J's validity (see Table 1). Twelve questions were selected from Takeuchi's SDQ-S (1992) and six questions related to spatial skills in everyday life were added. For each test item, participants were asked to rate their spatial skills on a five-point scale: 5 (strongly agree) to 1 (do not agree).

The SESS consists of eighteen questions classified into three groups. The first group concerns survey mapping, and contains six questions intended to measure awareness of orientation. The second group examines route mapping, and comprises six questions to assess one's ability to memorize landmarks in order to navigate an environment. The third group contains six questions concerning spatial reasoning in everyday life, particularly in small-scale environments.

Table 1 The questions of SESS

ID	Question
#1	I become confused as to cardinal directions, when I am in an unfamiliar place.
#2	When I get route information, I cannot make use of cardinal directions.
#3	It is difficult to understand the line of the train in cardinal directions.
#4	I cannot make out which direction my room in a hotel faces.
#5	I can easily find the place where I am on a map.
#6	I cannot grasp distance expressed in meters or kilometer units.
#7	I cannot use landmarks in wayfinding.
#8	I cannot remember landmarks found in the area where I have often been.
#9	I cannot remember the different aspects of sceneries.
#10	I often forget which direction I turned.
#11	I do not verify landmarks in a turn of the route.
#12	On the apparent similar road, I can distinguish a difference immediately.
#13	I can easily recreate an origami piece after watching someone else make it.
#14	I can pack a bag and a suitcase with baggage well.
#15	I can easily assemble a model and electrical appliance according to manual.
#16	I can easily visualize my room with a different furniture arrangement.
#17	I am good at playing ball games.
#18	I am good at playing board games (e.g., shogi, igo and chess).

Personal attributes and participants

Personal attributes potentially related to spatial thinking abilities were also examined by the questionnaire. The following attributes were used to identify determinants of spatial thinking abilities: degree of interest in everyday activities (e.g., geographical study, map use, outdoor activities, vehicles, travel, and computers), experience in geography education (e.g., field of study or completion of high school geography), and gender. One hundred university students participated in the experiment, of which 60 were male and 40 female; 25 were geography majors, while the remaining 75 were not. The questionnaire was completed within a 20-minute period during a geography class.

3. Components of Spatial Thinking Abilities

To examine reliability in terms of internal consistency, Cronbach's alpha coefficient was calculated. The alpha value was 0.500, which was less than the acceptable reliability level of 0.7. However, correlations between the total score and the score for each question were significantly large (Table 2). Except for Q6, test scores were not significantly correlated, thus indicating the test items' independence. Since Q6 entailed a relatively abstract task involving a Boolean operation, this item of overlaying probably required the basic spatial ability underlying other test items. This result supports Lee and Bednarz (2012) and Ishikawa's (2013) assertion that several different components comprise spatial thinking abilities.

Table 2 Rank correlation coefficient between scores of spatial thinking tests

	Q1	Q2	Q3	Q4	Q5	Q6
Q2	0.119					
Q3	0.090	0.117				
Q4	0.091	0.084	-0.003			
Q5	0.022	-0.031	0.040	0.243*		
Q6	0.110	0.160	0.240 *	0.294 **	0.202 *	
Total score	0.456 **	0.313 **	0.270 **	0.577 **	0.596 **	0.625 **

** Significant at 0.01 level, * Significant at 0.05 level.

Concerning the SESS, factor analysis was employed to identify the test scores' underlying dimensions. Three factors accounting for 51% of the total variance were obtained based on the "elbow" on the scree plot graph. These factors were interpreted based on the factor loadings in Table 3, in which absolute values greater than 0.3 are indicated in bold. Factor 1 concerns survey mapping, which is closely related to awareness of orientation. Factor 2 represents route mapping, which involves the memorization of landmarks in order to navigate an environment. Factor 3 concerns spatial reasoning in everyday life, particularly in small-scale environments.

To examine the relationship between the STAT-J and the SESS, Spearman's rank correlation coefficient was calculated. As shown in Table 4, there was no clear correspondence between most of the STAT-J and SESS items. Only Factor 1 (survey mapping) of the SESS significantly correlated with Q4 (spatial correlation) and Q5 (visualization) of the STAT-J.

Table 3 Factor loadings after the Varimax rotation

Question ID	Factor 1	Factor 2	Factor 3
#1	**0.8714**	0.2004	-0.0076
#2	**0.9053**	0.1099	0.0592
#3	**0.8059**	0.2159	0.2070
#4	**0.7346**	0.1688	0.2303
#5	**0.4990**	0.0958	0.2644
#6	**0.4214**	**0.3458**	0.2038
#7	**0.4107**	**0.3458**	0.1980
#8	0.1662	**0.6582**	0.2889
#9	0.1482	**0.7290**	0.2046
#10	**0.3287**	**0.6957**	0.1118
#11	0.0425	**0.3710**	-0.0889
#12	**0.3554**	**0.3632**	0.0423
#13	-0.1337	0.1769	**0.4078**
#14	0.1471	0.0088	**0.4729**
#15	0.2280	0.0515	**0.7126**
#16	0.0964	0.0688	**0.4137**
#17	0.0882	0.2389	**0.4249**
#18	0.1236	-0.0932	0.2010
Variance	31.46%	10.70%	9.18%

Absolute values greater than 0.3 are indicated in bold.

Table 4 Rank correlation coefficient between the STAT-J and the factor score of SESS

	Q1	Q2	Q3	Q4	Q5	Q6
Factor 1	0.137	0.031	-0.008	0.317**	0.236*	-0.055
Factor 2	-0.045	0.034	-0.148	0.020	0.041	-0.037
Factor 3	0.066	-0.043	-0.007	0.112	0.071	0.158

** Significant at 0.01 level, * Significant at 0.05 level.

4. Determinants of Spatial Thinking Abilities

Effects of personal attributes

To identify the determinants of spatial thinking abilities, statistical tests were created to examine differences in test scores according to participants' personal attributes. Figure 2 shows respondents' STAT-J test scores divided by major (geography or other). The test scores of respondents majoring in geography were higher than those of students majoring in other fields, especially for Q4 (spatial correlation) and Q5 (visualization).

A similar difference in test scores between groups was observed according to their experience with geography at the high school level. Figure 3 shows that respondents who studied geography during high school scored higher than those who did not, especially for Q4 (spatial correlation) and

Q5 (visualization). These results imply that geography education has an influence on students' ability to compare spatial patterns and transform 3-D and 2-D images.

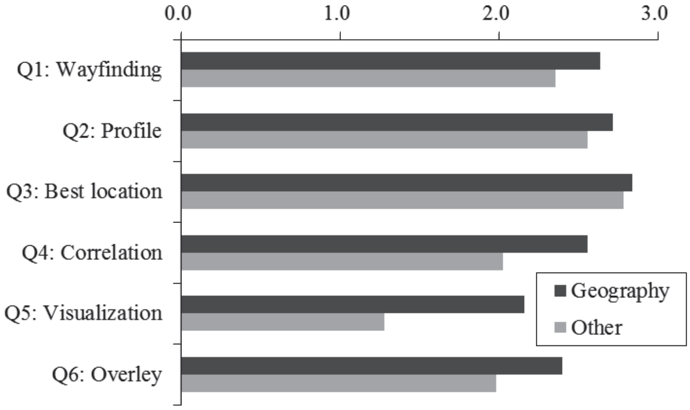


Fig. 2 Mean test scores by major field of respondents.

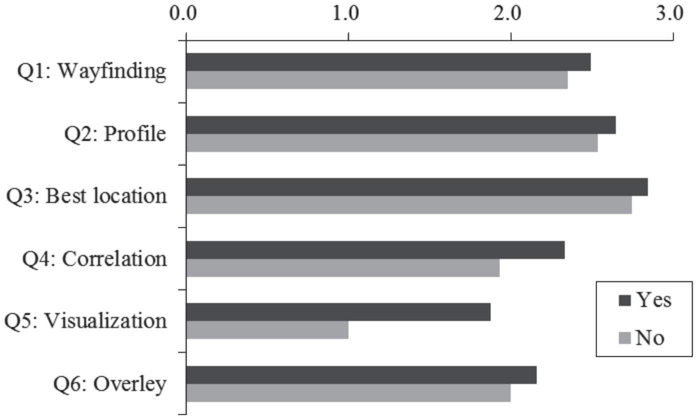


Fig. 3 Mean test scores by experience of high school geography.

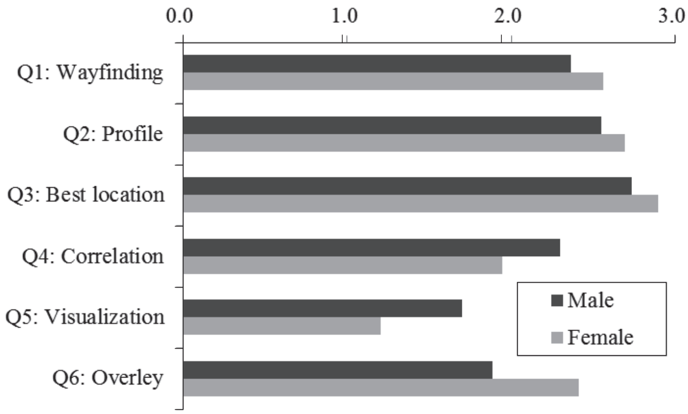


Fig. 4 Mean test scores by gender.

With regard to gender, little difference was observed except for Q5 and Q6 (see Fig. 4). Males outperformed females in answering Q5 (visualization), which is consistent with prior psychological research wherein males excelled in mental rotation tests. However, females outperformed males in answering Q6 (overlay); this could be related to findings that suggest superior spatial location memory in females. Nonetheless, there was no clear gender difference reflected in the test scores.

Effects of degree of interest

To examine the effect of respondents' degree of interest in everyday activities a correlation coefficient and statistical test was conducted. The results are summarized in Fig. 5, wherein a line between items indicates a statistically significant relationship. Interconnections are evident between activities of interest: in particular, interest in map use, geography, vehicles, and outdoor activities are closely related to the other items. These activities are also connected to the Factor 1 score, which is closely related to survey mapping. The other two factors, however, have no significant connection with the activity items.

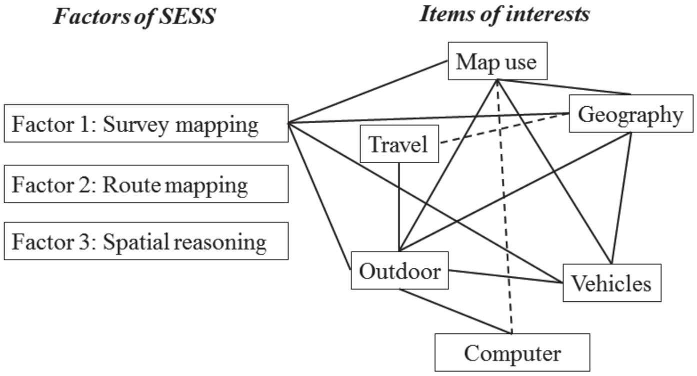


Fig. 5 Relationship between the degree of interest and factors of the SESS.
Dashed line: significant at 5% level, Solid line: significant at 1% level.

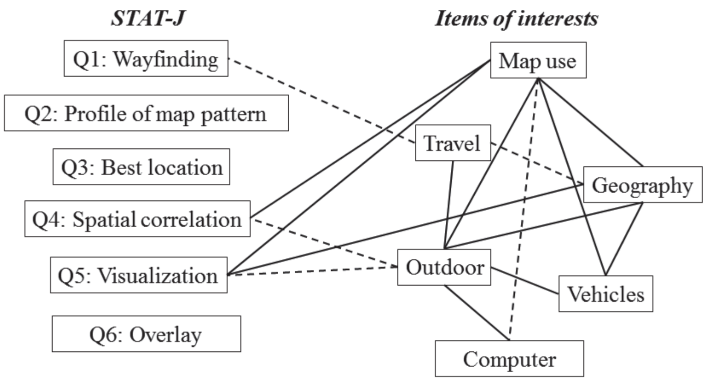


Fig. 6 Relationship between the degree of interest and scores of the STAT-J.
Dashed line: significant at 5% level, Solid line: significant at 1% level.

Concerning the relationship between the activities and STAT-J scores, Q4 (spatial correlation) and Q5 (visualization) had a significant relationship with map use, geography, and outdoor activities (see Fig. 6). As we expected, however, Q1 (wayfinding) was solely related to interest in travel. Among interests, interest in computers had little relationship to other interests or STAT-J /SESS test scores. This implies that interest in computers is not necessarily related to spatial thinking abilities.

5. Conclusion

This study examined various factors affecting performance on spatial thinking abilities tests by employing a Japanese version of the STAT and SESS. The results are summarized as follows:

1. At least six different components comprise spatial thinking abilities, as mentioned by Lee and Bednarz (2012) and Ishikawa (2013).

2. Spatial skills in everyday life can be assessed by the SESS, which is composed of three factors. The relationship between the STAT-J and SESS, however, is limited.

3. Some aspects of spatial thinking abilities (e.g., spatial correlation and visualization) are greatly affected by prior geography education, as well as interests in specific everyday activities (e.g., map use, geography, and outdoor activities).

Future research should consider the following issues. First, it is necessary to adjust the difficulty of the test questions since the degree of difficulty can affect respondents' answers. Second, because significance level of statistical test depends on the size of samples, a larger sample and greater variation among participants is needed. Third, the self-evaluation test should be revised to develop a more comprehensive version that covers a wider range of test items.

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(* in Japanese with English abstract)