Variation of geospatial thinking in answering geography questions based on topographic maps

Yoshiki Wakabayashi*, Yuri Matsui**

* Tokyo Metropolitan University
** Itabashi-ku, Tokyo

Abstract. This study explores the implications for geospatial thinking by examining its variations and processes in answering geographic questions based on topographic maps, and revealing the factors affecting this process. The study materials comprised seven questions on various types of topographic maps drawn from geography test questions in Japanese university entrance examinations. A quantitative analysis was conducted on answers obtained from 118 undergraduate students. These answers pertained to the relationship between performance on the test, experience of geography education, and spatial abilities. In addition, think aloud verbal protocols were obtained from ten students to analyze the detailed process behind their answers. The results indicated that the effects of experience of geography education and spatial abilities on the students' test performance varied with the type of questions. Qualitative analysis of the verbal reports confirmed that the cognitive process of reading topographic maps varied with the types of questions and maps. The findings imply that higher-order geospatial thinking based on topographic maps requires not only bottom-up processing of information on the map but also top-down processing that involves schemata containing geospatial knowledge based on one's prior experience or education.

Keywords: Map reading, Topographic maps, Geospatial thinking, Spatial abilities, Geography education

1. Introduction

Geospatial thinking has attracted interest in the fields of cartography and geographic information science especially after the publication of a report

entitled “Learning to think spatially” (NRC 2006). Map reading, in particular, is a fundamental skill not only for geography education but also for geospatial thinking in everyday life. Numerous studies in cartography have concentrated on the process of reading topographic maps. These studies are included in the field of “cognitive cartography” (Blades and Spencer 1986; Montello 2002). While several studies have largely focused on the perception and cognition of limited elements of a map, such as contour lines and map symbols (Montello et al. 1994; Murakoshi 1994), few have examined the higher-order cognitive processes of geospatial thinking.

To examine the processes of higher-order geospatial thinking using maps, an entrance examination on geography is a useful tool. Since Japanese high schools use topographic maps as an important teaching aid for geography education, university entrance examinations frequently incorporate geography questions based on topographic maps. Hence, several studies employed these questions to examine the map reading process. Murakoshi and Kobayashi (2002; 2003) analyzed the process of reading topographic maps in the test for university admissions held by the National Center for University Entrance Examination (NCUEE) of Japan. They found that students answered the questions using both deductive and inductive reasoning on the basis of geographical schema of generic knowledge of geography and morphology. Wakabayashi (2013) also dealt with various types of maps, ranging from large-scale topographic maps to small-scale thematic maps, to examine the relationship between the map reading process, spatial abilities, and experience of geography education.

However, little is known about variations in the process of reading topographic maps and the factors affecting this process. This study examines the variations and processes of geospatial thinking involved in answering a variety of geographic questions based on topographic maps, and reveals the factors affecting this process to explore the implications for geospatial thinking.

2. Methodology and Data

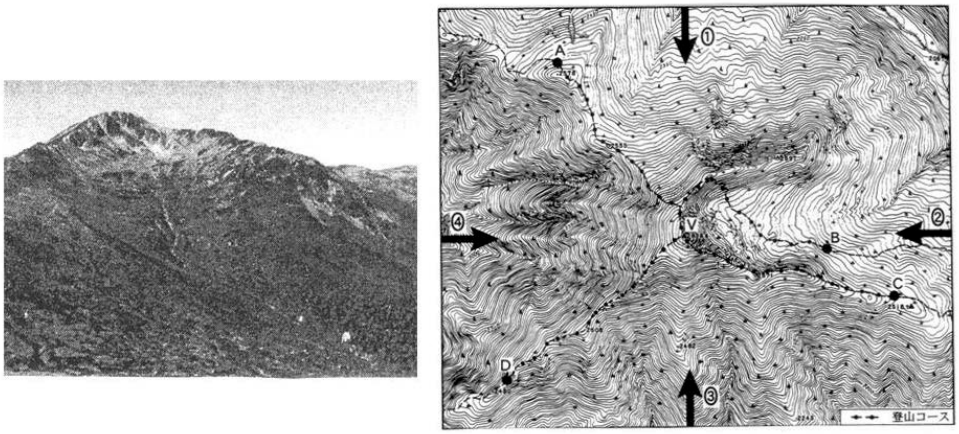
2.1. Materials

This study analyzed geography test questions used in university entrance examinations held by the NCUEE of Japan. An analysis of the questions included in the NCUEE tests of the past 20 years revealed a change in the

trend of the questions after 2000. Questions about change in land use or landform through comparison of old and new maps have increased, while those on visualizing landscape and identifying typical landforms based on topographic maps have decreased. This change partially reflects a shift in the emphasis of Japanese school curriculum guidelines from memorization to reasoning and independent thinking.

For experiment and questionnaire in this study, seven questions about various types of topographic maps were selected: association of a contour map with a photograph (Question 1), drainage estimation (Question 2), judgment of landform classification (Question 3), and comparison between old and new topographic maps (Questions 4-1 to 4-4).

- Question 1 (Q1): Select the vantage point that commands a view shown in a picture (Figure 1(a)) from among four directions (Figure 1(b)).
- Question 2 (Q2): Choose a location within a dammed drainage basin from among four points (a, b, c, and d in Figure 2).
- Question 3 (Q3): Identify the landform types shown in topographic maps. Respondents are required to choose a map representing a karst area from among four maps (Figure 3).
- Question 4 (Q4-1 to Q4-4): Judge whether a sentence comparing a pair of old and new maps is true or false. The sentence is mainly concerned with the change of land use or landform observed in the topographic map (Figure 4).



(a) (b)

Figure 1. Picture and map used in Question 1

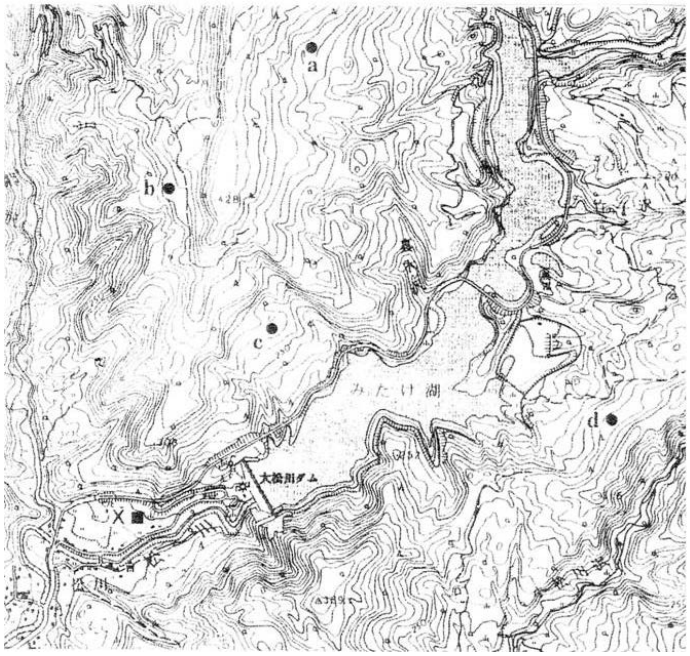


Figure 2. Map used in Question 2

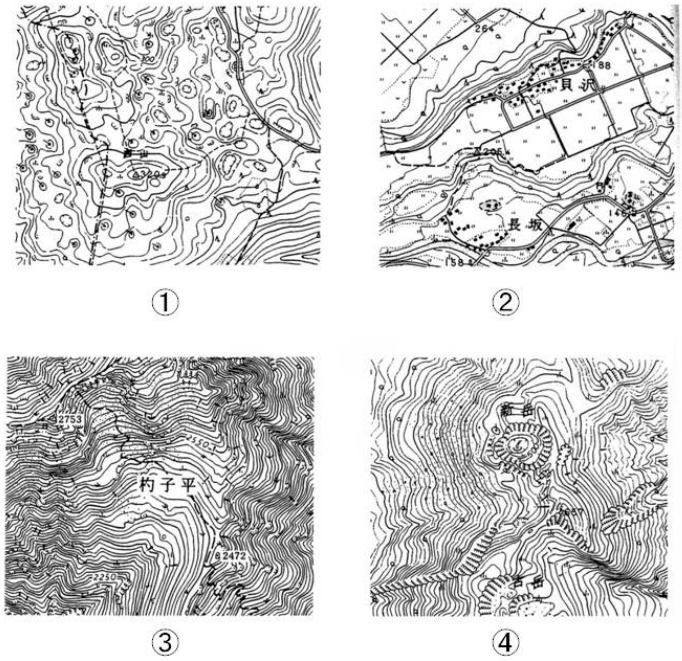


Figure 3. Map used in Question 3

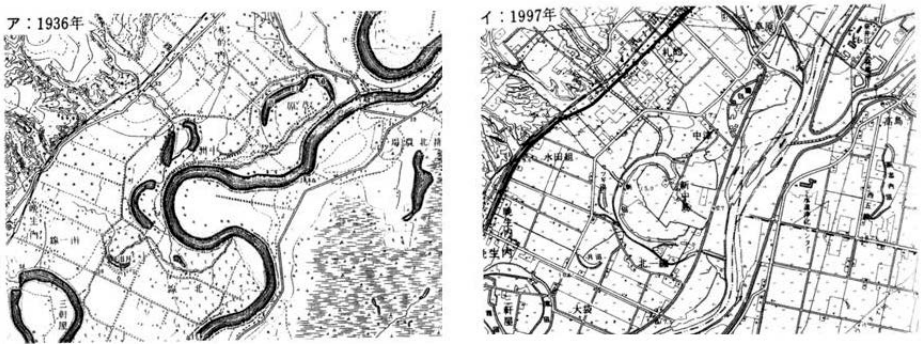


Figure 4. A pair of old and new maps used in Question 4-2

2.2. Procedure

A mixed-method approach combining quantitative and qualitative data and analyses was adopted. A questionnaire survey was conducted with 118 undergraduate students (male, 67; female, 51) for the quantitative analysis. Forty-nine of the total respondents majored in geography. The questionnaire attempted to find the students' pattern in answering these questions and verify the factors affecting this pattern. To quantify the test performance of the respondent for each question, scores were given according to the quality of answers. Data obtained were analyzed quantitatively with regard to the relationship between performance on the test, experience of geography education, and spatial abilities. To analyze the detailed process behind their answers qualitatively, an experiment was conducted in which think aloud verbal protocols were obtained from ten undergraduate students (male, 6; female, 4) who did not participate in the questionnaire survey.

3. Quantitative Analysis of the Questionnaire Data

3.1. Patterns in answers

Factor analysis of answers to the questions yielded three factors (Table 1). Factor 1 is correlated with the questions of comparison between new and old maps (Q4-2, Q4-3, and Q4-4), thereby pertaining to the ability to comprehend temporal change in the earth's surface by reading the topographic map. Factor 2 is correlated with the questions requiring reading of contour lines (Q1, Q2, and Q3), indicating its link to visualization of landform based on the contour line. Factor 3 is solely related to the question of land use

change (Q4-1). Considering that the percentage of correct answers is highest in Q4-1, Factor 3 is likely to involve a relatively simple task of recognizing map symbols. Thus, the pattern in answers to the questions can be classified into three types.

Table 1. Factor loadings after the varimax rotation. Boldface letters show absolute values of factor loadings not less than 0.5.

Test question	Factor 1	Factor 2	Factor 3	Percentage of correct answers
Q1 Map and picture	0.029	**0.662**	**0.545**	51.7
Q2 Drainage area	0.468	**0.651**	−0.129	54.2
Q3 Typical landform	0.169	**0.817**	0.055	44.9
Q4-1 Land use change	0.269	0.004	**0.859**	66.1
Q4-2 Navigable river	**0.743**	0.112	0.323	50.8
Q4-3 Housing development	**0.799**	0.139	0.123	57.6
Q4-4 Alluvial fan & arable land	**0.653**	0.462	0.084	44.1
Variance (%)	27.7	25.3	16.9	−

3.2. Factors affecting the pattern in answers

The relationship between the patterns in answers to the questions and the attributes of the respondents was examined using Spearman's rank correlation statistics (Figure 5). In this analysis, spatial abilities were measured using 13 questions selected from the Sense of Direction Questionnaire-Short Form (SDQ-S) developed by Takeuchi (1992). We calculated the scores of two factors used in SDQ-S, i.e., awareness of orientation, closely related to survey mapping ability and memory for normal spatial behavior, representing route mapping ability. In addition, we designated the experience of geography education at high school/university and preparation for university entrance examinations as respondents' educational level of geography.

The result, summarized in Figure 5, indicates that the effects of experience of geography education and spatial abilities on the students' test performance vary with the type of questions. Although this highlights the difference between the knowledge and skills required to read topographic maps, the experience of geography education had a significant effect on the answers. Concerning spatial abilities, survey mapping ability has a direct effect on the test performance of Factors 1 and 2, while the effect of the route mapping ability is indirect and limited. No significant effect on Factor 3 is

observed probably because the pattern of answering Question 4-1 shows no pronounced tendency owing to its simplicity.

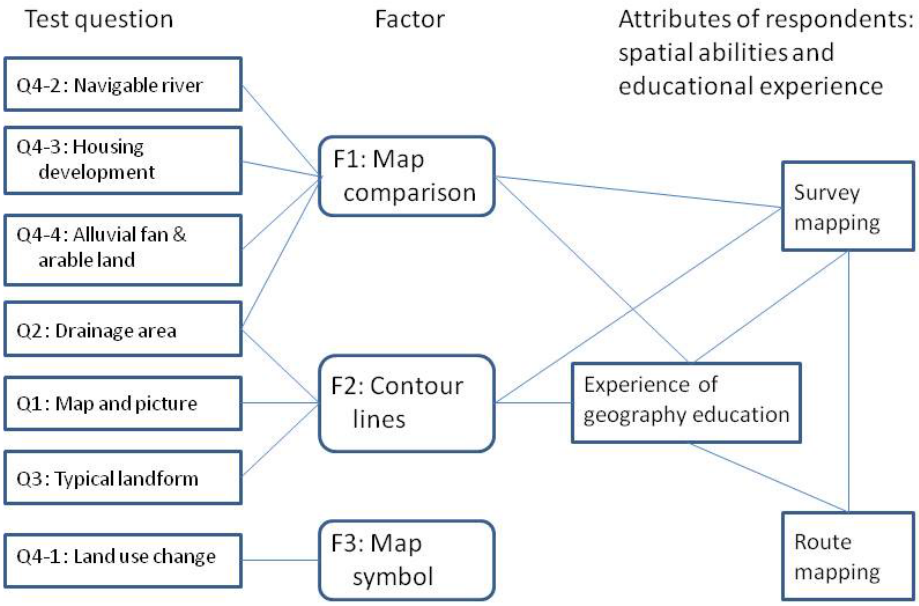


Figure 5. Relationship between the pattern in answering test questions and the attributes of respondents. Lines show relationships in which Spearman's rank correlation coefficient is 0.3 or more.

4. Qualitative Analysis of Verbal Protocols

An additional experiment was conducted to examine the detailed processes of reading maps and answering questions. Qualitative analysis of the verbal reports obtained from ten students revealed that the cognitive process of reading topographic maps varied with the types of questions and maps. A detailed analysis of the verbal protocols shows that these questions could be classified into four types on the basis of knowledge and skills required for the answers.

First, Question 4-1 solely asks respondents to relate the description of a feature (e.g., mulberry field, rice paddy) described in a sentence to the symbol on the topographic map (Figure 6); this corresponds to Factor 3 mentioned above. The fact that the percentage of correct answers to this question is the highest among the seven questions indicates the simplicity in demanding recognition of map symbols.

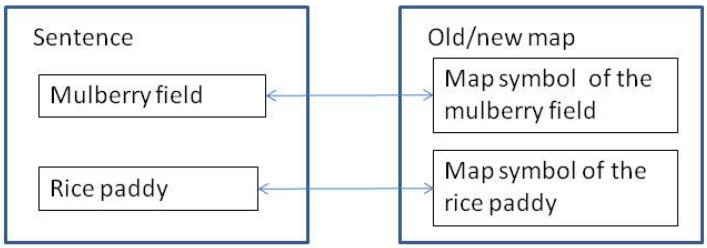


Figure 6. Schematic representation of the map reading process based on verbal protocol: a case of Question 4-1

Second, Questions 1 and 2 can be answered on the basis of basic spatial abilities (e.g., visualization and mental rotation) and the knowledge of contour maps; these are closely related to Factor 2. For example, the cognitive process of a respondent solving Question 1 is schematically represented in Figure 7. The respondent noticed the left-hand side crest of a ridge on the picture and directed attention to the elevation of a triangulation point on the contour map. Then he associated the long intervals of contour lines at the east side ridge with the gentle slope at the front side on the picture.

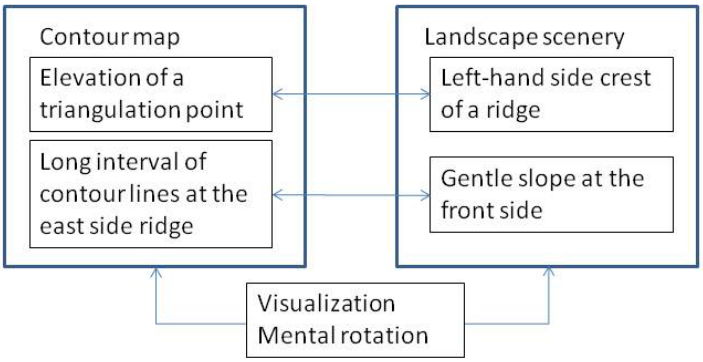


Figure 7. Schematic representation of the map reading process based on verbal protocol: Question 1

Third, Question 3 asks respondents to relate geographic concepts with features on the map, which is also related to Factor 3. For example, a respondent answered this question on the basis of a kind of schematic knowledge of the landform type (e.g., karst) by imagining the features of the landform (e.g., limestone, doline, depression). The respondent then searched for a small-scale depression, which is a distinctive feature of karst, on the topographic map (Figure 8). This involves both top-down (conceptually driven)

and bottom-up (data driven) cognitive processes (Murakoshi and Kobayashi 2002; 2003). If either of these processes is erroneously followed, one cannot answer correctly.

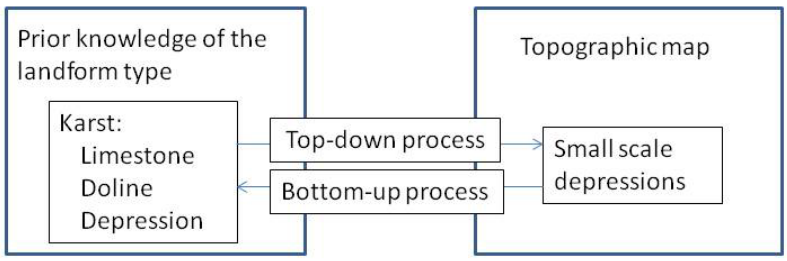


Figure 8. Schematic representation of the map reading process based on verbal protocol: Question 3

Fourth, Questions 4-2, 4-3, and 4-4 require specification and inference of the changes on the earth's surface; this corresponds to Factor 1. Respondents answered these questions by reading not only contour lines but also various map symbols to infer changes in the earth's surface on the map. For example, a respondent translated the elements of a sentence describing old and new maps (e.g., agrarian land use, navigable for large ships, thermal power station) into symbols and their patterns on the map (Figure 9).

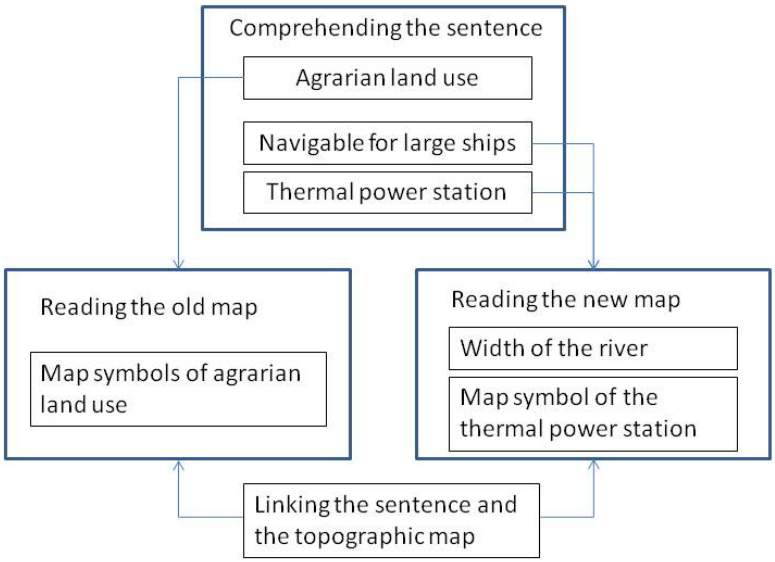


Figure 9. Schematic representation of the map reading process based on verbal protocol: Question 4-2

The respondent then looked for the symbols of agrarian land use on the old map; he specified the river's width on the basis of the map scale and searched for the symbol of the thermal power station on the new map. This process elucidates that the cognitive process of comparing old and new maps involves higher-order geospatial thinking, which requires top-down and bottom-up processing of spatial information in verbal descriptions and maps.

5. Conclusion

The study results revealed that the cognitive process of reading topographic maps varied with the types of questions and materials used in our analysis. For example, questions about the correspondence between a verbal description and map require relatively simple thinking to understand the meaning of map symbols. The questions on reading contour lines require basic spatial abilities (e.g., visualization, mental rotation). In contrast, questions concerning the identification of landform type and comparison between old and new maps require higher-order geospatial thinking, which involves not only bottom-up processing of information on the map but also top-down processing based on schemata containing geospatial knowledge drawn from one's prior experience or education.

With regard to the elements of spatial thinking (NRC 2006), the factor analysis result confirms the existence of the independent spatial thinking components pointed out by Lee and Bednarz (2012). In particular, the process of reasoning, an element of spatial thinking, is closely related to the last type of question requiring respondents to infer invisible facts from visible information on the map. This process of reasoning accompanies not only basic spatial abilities but also the schematic knowledge of geographic concepts. Hence, both experience of geography education and spatial abilities influence the performance of answering this type of question, as shown in Figure 5.

In this way, various levels of geospatial thinking can be tested using a topographic map. Hence, questions and maps appropriate to the level of learners should be used for proper training in geospatial thinking. This study supports Ishikawa's (2013) view that geospatial education must allow for different levels of learning, from basic background knowledge to higher level reasoning. Further effort is needed to examine how digital maps based

on geographic information systems, which have taken the place of paper maps, can improve the educational effects of geospatial thinking.

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