CO-110

ROLE OF GEOGRAPHIC KNOWLEDGE AND SPATIAL ABILITIES IN MAP READING PROCESS: IMPLICATIONS FOR GEOSPATIAL THINKING

WAKABAYASHI Y.
Tokyo Metropolitan University, HACHIOJI-SHI, JAPAN

1. INTRODUCTION

Since the National Research Council (NRC) in the United States published a report entitled "Learning to think spatially" (NRC 2006), the relationship between GIScience (Geographic Information Science) and spatial thinking has attracted interest in English-speaking countries. It is certain that geospatial thinking is founded on spatial abilities consisting of spatial visualization, spatial orientation, and spatial relations (Golledge and Stimson, 1997). However, further investigation is needed to clarify the influence of spatial abilities on spatial thinking (Hegarty and Waller, 2004).

In particular, map reading is closely related to the elements of spatial thinking (i.e., concept of space, reasoning process, and representational tools) (NRC 2006). Numerous attempts have been made to understand the map reading process in the fields of cartography and psychology. These studies are included in a field called "cognitive cartography" (Montello, 2002), which encompasses the application of cognitive theories and methods to understand maps and mapping processes, as well as the application of maps to understand spatial cognition. The findings of cognitive cartography can be useful for facilitating geospatial thinking.

Nevertheless, because previous studies mainly focused on the process of creating effective maps while dealing with the perception and cognition of the elements of a map, little is known about the higher order cognitive processes used in recognizing the total content of a map in the context of geographic problem solving. In addition, recent studies on the map reading process have diverted attention to navigational maps (e.g., Lobben, 2004, 2007); however, few studies (excluding some exceptions e.g., Kulhavy et al., 1992; Michaelidou et al., 2004) have used various maps, including small-scale thematic maps.

To examine various aspects of the processes of geospatial thinking using maps, an entrance examination on geography can serve as a useful tool because it contains various types of maps and examines map reading abilities synthetically. For example, Murakoshi and Kobayashi (2002, 2003) examined the process of reading topographic maps in the National Center Test for University Admissions. 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. However, whether this finding is applicable to map reading of small-scale thematic maps is uncertain.

The purpose of this study is to examine the cognitive processes used to solve geographical questions that require map reading tasks in order to explore implications for geospatial thinking. In particular, this study deals 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 and the spatial abilities, along with the experience of geography education.

2. METHODS

2.1 Participants

Data used in this study were obtained from a questionnaire including test questions on geography, followed by an experiment on the process of answering the questions. The respondents to the questionnaire included 139 undergraduate students who attended a lecture on human geography at the Tokyo Metropolitan University. The respondents consisted of 114 males and 25 females; 80 students majored in humanities whereas the others specialized in science. They answered the questionnaire in the classroom during the same lecture session. In addition, 12 undergraduate students (nine males and three females), who were not included in the respondents of the questionnaire survey, participated in the experiment individually.

2.2 Materials

The materials for this study were obtained from the test questions in geography used in the entrance examination of the National Center for University Entrance Examinations of Japan (NCUEE). The NCUEE administers the National Center Test for University Admissions in Japan under the control of the Ministry of Education, Culture, Sports, Science and Technology. Numerous test questions on geography in the National Center Test include maps of various scales and subjects. We selected six questions regarding three types of maps of different scales and subjects (e.g., large-scale topographic maps and small-scale thematic maps) as the materials for the subsequent questionnaire and experiment. The questionnaire consisted of multiple-choice questions; following are the details:

Question 1 is based on the locations within a viewshed from a ridge (Q1-1) and drainage basin (Q1-2) on a large-scale topographic map. The topographic map contains complicated contour lines and elevations with few place names (Fig. 1). Q1-1 requires respondents to select the location that is invisible from a mountaintop (X in Fig. 1) among four points (from "ア" to "エ"). Q1-2 requires to select the location outside the drainage area among four points from "a" to "d" (Y in Fig. 1).

Question 2 is based on the width of the Indian Ocean in kilometers (Q2-1) and the type of underground resource (Q2-2) shown in the small-scale map of the region surrounding the Indian Ocean. The map contains meridians, parallels, and major sites of an underground resource (Fig. 2). Q2-1 and Q2-2 require respondents to select the optimum value of the width of the Indian Ocean and the kind of resource among four choices, respectively.

Question 3 is based on the kinds of demographic properties of a prefecture shown in two choropleth maps of Japan (Fig. 3). These maps represent population density (Q3-1) and the proportion of the aged population (Q3-2) with three symbols for classes of quantile. Both questions require respondents to select the answer from five choices.

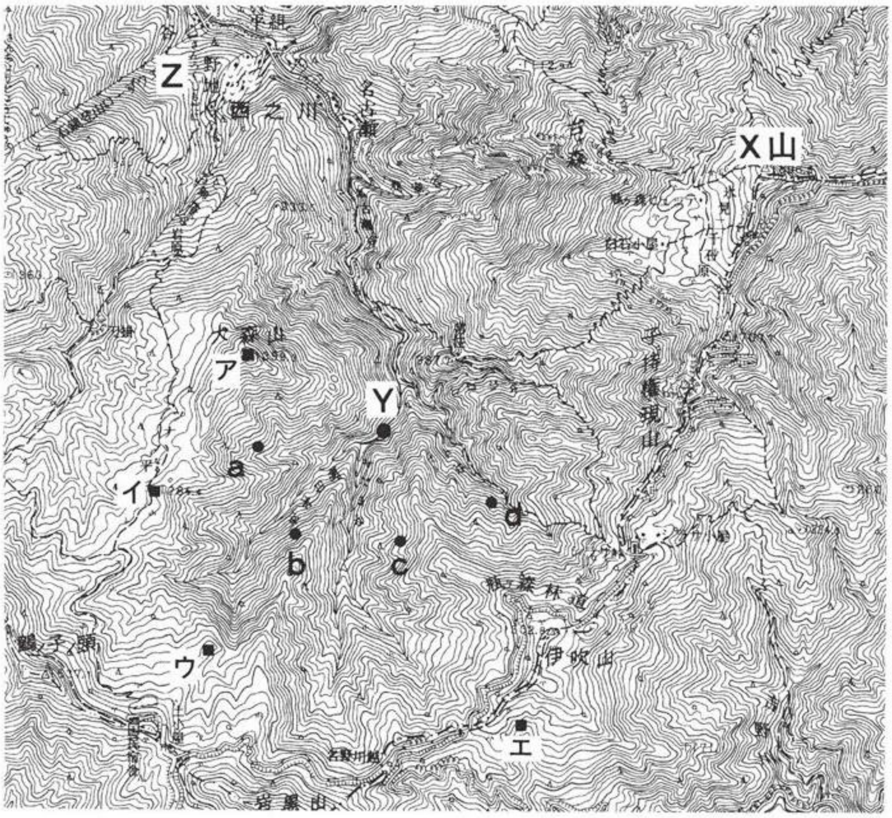

Fig. 1 Topographic map used in Q1-1 and Q1-2

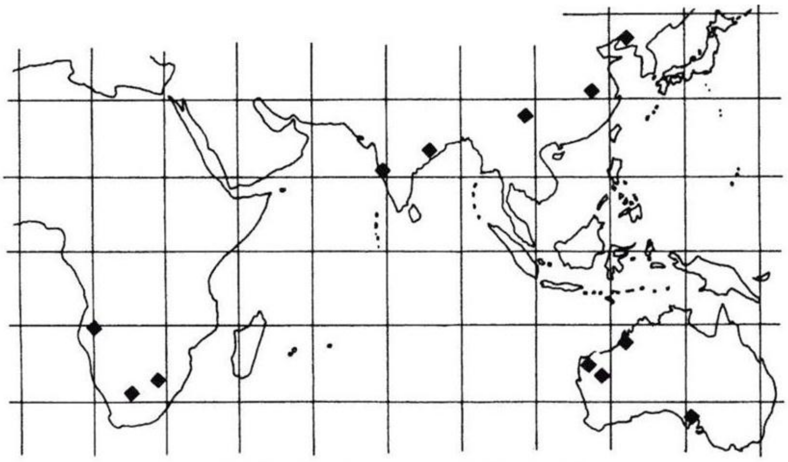

Fig.2 Small-scale map used in Q2-1 and Q2-2

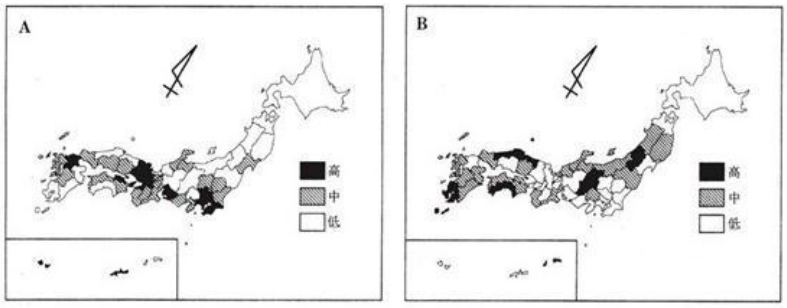

Fig. 3 Choropleth maps used in Q3-1 and Q3-2

2.3 Procedure

This study adopts a multiple-method approach combining quantitative and qualitative data and analyses. The questionnaire data concerning the answers to the geography questions were quantitatively analyzed. Participants were required to rate their spatial abilities by self-evaluation of their sense of direction on a five-point scale, and note whether they had selected a high school geography course, because it is an optional subject in Japanese high schools. The answers for the questionnaire were obtained from 139 university students and analyzed quantitatively with regard to the relationship among performance on the test, experience of geography education, and self-evaluation of spatial abilities.

To examine the detailed map reading process, we also applied a "think aloud" method (Suchan and Brewer, 2000; Kulhavy et al., 1992) wherein 12 students described their cognitive processes for answering the questions identical to those included in the questionnaire. We recorded these verbal reports with an IC recorder and analyzed their responses qualitatively to validate the results of the questionnaire survey.

3. QUANTITATIVE ANALYSIS OF THE QUESTIONNAIRE DATA

Table 1 shows the relationship between answers to the questions recorded as correct or incorrect and profiles of the students (experience of high school geography education, subject of specialization, and sense of direction) using a chi-square test.

The relationship between their experience of high school geography education and performance on questions Q1-1, Q1-2, and Q2-1 are significant at 0.01 level. This indicates that skills for reading topographic maps and knowledge of world regional geography were acquired through high school geography. In contrast, the experience of high school geography shows no significant effect on answering Question 3. This can be attributed to the content of high school geography; all students learn the geography of Japan relevant to Q3-1 and Q3-2 in junior high school, where geography is a compulsory subject.

Table 1 Comparison of the percentage of correct answers between attributes of the respondents

Ques-tion	Content	Completion of high school geography		Specialization		Sense of direction	
		No	Yes	Human-ities	Science	Low	High*
Q1-1	Viewshed	34.3	59.4 **	41.3	54.2	45.2	48.5
Q1-2	Drainage area	21.4	69.6 **	32.5	62.7 **	34.2	57.6 **
Q2-1	Width of the Indian Ocean	14.3	43.5 **	18.8	42.4 **	26.0	31.8
Q2-2	Underground resource	38.6	69.6 **	52.5	55.9	47.9	60.6
Q3-1	Population density	64.3	66.7	65.0	66.1	63.0	68.2
Q3-2	Proportion of the aged population	77.1	85.5	77.5	86.4	80.8	81.8
	Number of samples	70	69	80	59	73	66

Except the number of samples, other values indicate percentages of correct answers.

* High denotes "exceptionally good" or "relatively good" sense of direction.

** Significant at 0.01 level according to the chi-square test.

The students' subject of specialization causes significant difference in their performances on Q1-2 and Q2-1. Q1-2 requires the students to estimate the drainage area by interpreting the contour lines on the map, whereas Q2-1 requires the students to calculate the width of the Indian Ocean based on the knowledge of the size of the Earth and the distance between latitude and longitude locations. Because these skills and knowledge are closely related to science, students who major in science can answer these questions better than those who specialize in humanities.

Concerning the self-evaluation of one's sense of direction, a significant effect is detected solely in the answers to Q1-2. As mentioned above, this question requires students to visualize topography from the pattern of contour lines. Such a skill is included in spatial abilities (Golledge and Stimson, 1997), which is also relevant to the sense of direction. Hence, understanding topographic maps can involve some elements of spatial abilities.

Table 2 shows the relationship between the answers to the questions evaluated with the phi coefficient. The chi-square test for these coefficients detects significant correlation among Q1-1, Q1-2, and Q2-1. These questions commonly involve scientific knowledge and skills, as mentioned above. This indicates that cognitive requirements for map reading vary with the types of maps and questions.

Table 2 Relationship between the answers to the questions

Question	Content	Q1-1	Q1-2	Q2-1	Q2-2	Q3-1
Q1-1	Viewshed	–				
Q1-2	Drainage area	0.421 **	–			
Q2-1	Width of the Indian Ocean	0.169 *	0.251 **	–		
Q2-2	Underground resource	0.027	0.116	0.173 *	–	
Q3-1	Population density	0.105	0.053	-0.040	-0.155	–
Q3-2	Proportion of the aged population	0.043	0.103	0.020	0.075	0.001

Numbers in this table indicate the phi coefficient.

* Significant at 0.05 level according to the chi-square test.

** Significant at 0.01 level according to the chi-square test.

With regard to the interrelation among the profiles of the respondents, there is significant correlation among the experience of high school geography, subject of specialization, and sense of direction (Table 3). In particular, students who completed a high school geography course tend to evaluate their sense of direction higher. This implies that the opportunity to use maps in a geography classroom enhances students' spatial abilities. In addition, Table 3 also shows that students who completed high school geography tend to specialize in science. This fact is supported by the report of the NCUEE that Japanese candidates for science majors tend to select geography rather than history in the entrance examination, which indicates an affinity of geography for science.

Table 3 Contingency table between the profiles of the respondents

Experience of high school geography	Specialization		Sense of direction	
	Humanities	Science	Low	High*
No	53	17	44	26
Yes	27	42	29	40
	Chi-square = 19.037 $p < 0.001$		Chi-square = 6.045 $p < 0.05$	

* High denotes "exceptionally good" or "relatively good" sense of direction.

4. QUALITATIVE ANALYSIS OF VERBAL PROTOCOLS FROM THE EXPERIMENT

To examine the detailed processes of map reading and answering questions, we conducted an additional experiment. Twelve subjects who did not participate in the questionnaire survey provided "think aloud" data by describing the processes they used to answer the questions identical to those in the questionnaire. An analysis of the verbal protocols yielded the following findings (Table 4).

Concerning Q1-1 about the viewshed on a topographic map, only five out of 12 subjects answered correctly. Most of the subjects who answered incorrectly made mistakes in identifying ridges and valleys on the map. In contrast, subjects who answered correctly could trace the ridges and valleys by reading detailed elevations on the map. Although this question requires fundamental map reading skills to visually understand the topography from contour lines, few subjects answered correctly. This could be due to subjects' inexperience with this kind of question or could possibly be related to the order of the questions.

Eight subjects answered Q1-2 correctly, which implies that this question is easier than Q1-1. Most of the students answered correctly used the process of elimination on the basis of generic knowledge, such as "water flows downstream along valleys," to trace valleys while examining each choice carefully. In contrast, many subjects who answered incorrectly had no experience of high school geography and overlooked the pattern of topography owing to improper attention to local patterns of contour lines; some of them misunderstood ridges and valleys even if they knew how to solve the problem. In particular, specific knowledge of place names or their locations appears irrelevant to answer questions using topographic maps, because few place names appeared in subjects' verbal protocols.

Table 4 Summary of the experiment

Sub-ject ID	Sex	Special-ization	Sense of direc-tion*	High school geogra-phy	Answer to the question**						Number of correct answers
					Q1-1	Q1-2	Q2-1	Q2-2	Q3-1	Q3-2	
1	Male	S	High	Yes	X	X	X	X	X	X	6
2	Male	S	High	Yes	X	X	X	X	X	X	6
3	Male	H	Low	No	X	X	X	X	X	X	6
4	Male	S	High	Yes		X	X	X	X	X	5
5	Male	S	High	Yes	X		X	X	X	X	5
6	Female	S	High	Yes		X	X		X	X	4
7	Male	S	High	Yes		X	X			X	3
8	Male	S	High	Yes		X	X			X	3
9	Male	S	High	No		X			X	X	3
10	Female	S	Low	No	X	X				X	3
11	Female	H	Low	No				X		X	2
12	Male	H	Low	No					X	X	2

* "S" denotes Science; "H" denotes Humanities.

** High denotes "exceptionally good" or "relatively good" sense of direction.

*** "X" denotes the correct answer; blank denotes incorrect one.

Concerning Q2-1, which requires calculating the width of the Indian Ocean, seven subjects, who evaluated their sense of direction relatively high, answered correctly. Two strategies for determining the answer, called as local and global, can be identified from their verbal protocols. The local strategy is to estimate the distance based on their prior knowledge of the absolute location of Japan and its width, such as "standard meridian of Japan is at 135 degrees east," and "width of the Japanese Island is approximately 30 degrees." The global strategy is to estimate distance according to the circumference of the Earth or the distance per unit degree, such as "the circumference of the Earth is approximately 40,000 kilometers," and "one degree corresponds to 111 kilometers." In contrast, subjects who answered incorrectly did not have basic geography knowledge or were unaware of other strategies to answer the question. In particular, few subjects used the process of elimination to answer, whereas subjects who answered correctly provided rational reasoning based on their structural knowledge of geography.

Only six subjects, most of whom completed high school geography, answered Q2-2 correctly, which requires determining an underground resource located at marked sites. Subjects tended to answer using the process of elimination; subjects who hesitated to select "coal" or "iron ore" tended to answer on the basis of their knowledge of mines in Australia and China. In contrast, many subjects who answered incorrectly relied on inaccurate knowledge of the locations of mines, even if they knew the place names. Because this question requires specific (topographic) knowledge of the underground resources in the world, the answers can depend to a large extent on their experience of high school geography.

Eight subjects answered Q3-1 correctly, concerning the population density of Japan, irrespective of their experience of high school geography. The higher values in a metropolitan region on the map probably indicated the answer. While the subjects, who answered correctly, examined each choice carefully, some subjects inferred from naïve theories acquired through everyday life irrespective of its scientific validity, such as "small areas lead to high density." In contrast, subjects who answered incorrectly tended to confuse population density with daytime/nighttime population ratios and relied on an incorrect process of elimination. To answer this question, knowledge of the location of prefectures and the topography of Japan is required; many subjects could possess this kind of knowledge without a background in high school geography.

All subjects answered Q3-2 correctly, which is the easiest among the six questions. Many subjects used the process of elimination to answer this question. In particular, the subjects tended to connect higher values in the prefectures in northeast Japan or along the coasts of the Japan Sea to "population drain" and "aging." Because this kind of knowledge may be obtained through geography education in junior high schools or everyday life, the experience of high school geography had no significant effect on the answer to this question.

5. CONCLUSION

The results obtained in this study indicate that the process of answering questions on large-scale topographic maps is entirely affected by the spatial abilities of the respondents, whereas that of answering questions on small-scale thematic maps is closely related to general geographic knowledge and high school geography education. This can be due to the difference in the abilities required to answer the questions. The general scientific knowledge and the spatial ability of visualization, rather than the geographic knowledge of specific places, are important to answer the questions on large-scale topographic maps. In contrast, geographic knowledge of place names and their locations is indispensable to answer the questions on small-scale thematic maps.

As shown in this study, the knowledge and the skills required to answer the questions, including map reading, vary with the types of maps. In particular, the results imply that the role of idiographic knowledge is important particularly to answer geographic questions concerning small-scale thematic maps. This indicates a distinctive feature of geospatial thinking, compared with the importance of nomothetic knowledge in the subject of science studied in cognitive psychology (Suzuki et al., 1989).

Concerning the individual differences in answering the questions, students' experience of high school geography considerably affected their performances. This implies that learning with maps in a high school geography course can enhance geospatial thinking as well as spatial abilities. However, little is known about the influence of various aspects of spatial abilities on map reading process and spatial thinking in everyday life (Hegarty and Waller, 2004). In addition, idiographic knowledge (i.e., place names) can play an important role in reading large-scale maps of a familiar environment. These matters are open to further discussion.

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