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Impacts of geographical knowledge, spatial ability and environmental cognition on image searches supported by GIS software

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ABSTRACT

Google Earth search function was used to study the impacts of small-scale spatial ability, large-scale environmental cognition, and geographical knowledge on new technology usage. The participants were 153 junior high students from central Taiwan. Geography grades served as indicators of prior knowledge, mental rotation and abstract reasoning skills as indicators of spatial ability, and sketch maps of school neighborhoods as indicators of environmental cognition (including landmark representation, intersection representation, and frame of reference). Lastly, the authors announced the landmarks searching worksheet and asked the participants to accomplish 16 familiar and unfamiliar landmark searching tasks using Google Earth with keyword search function disabled. The result showed the strongest predictor of landmark searching performance is 'frame of reference' in environmental cognition, followed by 'mental rotation' of spatial ability, 'landmark representation' of environmental cognition, and geographical knowledge. Google Earth landmark searches require complex cognitive processing; therefore, our conclusion is that GIS-supported image search activities give students good practice of active knowledge construction.

1. Introduction

As internet technology advances, the forms of maps have transformed from traditional paper-maps to e-maps. Maps used for geography lessons are now less likely to be on paper and more likely to come in the form of e-maps, virtual reality maps, or 3-D spatial maps. E-maps become excellent tools to present information regarding eco-system and human societies as they are able to lay out the information more vividly and accurately than paper-maps. Whereas multiple paper-maps were required to show different features (geological terrain, transportation routes, administrative regions, etc.), advanced information technology tools allow for maps features to be layered upon each other or removed quickly. Meanwhile, they provide more user-friendly interfaces than traditional maps and make it more interactive as well as effective when they are adopted as teaching materials (Pickles, 1995). Some studies have started to examine the function and effectiveness of using GIS in classroom instruction. For example, Summerby-Murray (2001) suggests that providing geographic information system as visualization tool in college geography course can help college student's constructive learning. Broda and Baxter (2003) suggest that layering different map themes and visualizing complex mental rotation helps students develop spatial recognition and processing strategies.

A geographic information system (GIS) is computer system for performing geographical analysis; that computerized system captures, integrates, stores, edits, analyzes, shares, manages, displays, and represents data that refers to or is linked to spatial information (Encyclopaedia Britannica, 2009; Harvey, 2008). Through the process of geocoding, geographic data from a database is converted into images in the form of maps. A GIS includes not only hardware and software, but also the special devices used to input maps and to create map products, together with the communication systems needed to link various elements (Bernhardsen, 2002). GIS applications are tools that allow users to create interactive queries (user created searches); it communicates about human and environmental activities and events that take place on our planet (Harvey, 2008). GIS is frequently used by environmental and urban planners, marketing researchers, retail site analysts, water resource specialists, and other professionals whose work relies on maps (Encyclopaedia Britannica, 2009). A growing number of consumers are becoming familiar with GIS systems as navigation tools in their automobiles.

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The report from the National Research Council of the United States (Committee on Geography, NRC, 2006), "Learning to think spatially: GIS as a support system in the K-12 Curriculum," points to the critical value of introducing spatial thinking skills across subjects and to learners of all ages. Spatial thinking/enquiry is the knowledge and skills to use concepts of space, tools of representation like maps and graphs, and processes of reasoning to organize and solve problems. It is the process on understanding the meaning of space and using the properties of space as a medium to structure enquiry problems, to find answers, and to convey the solution and its process. NRC suggests that spatial thinking/enquiry is at the heart of many advanced discoveries in science. It supports many activities of the modern workforce and pervades the everyday activities of modern life. By visualizing relationships within spatial configurations, students can recognize, memorize, and analyze the static and the dynamic properties of objects and the relationships among objects. Skills of spatial enquiry can be learned and it can be taught in all educational levels from primary school to college. With advances in computational technology (such as GIS), spatial enquiry can now be supported in ways that enhance its speed, accuracy, and flexibility. Because of available information technologies, support for spatial enquiry is more readily possible today, but more challenging cognitive skills are necessary to take advantage of using the support systems.

Since GIS are now considered effective visualization aids in the teaching of spatial enquiry, they are becoming classroom learning tools in Taiwan and many other developing and developed countries (Meyer, Butterick, Olkin, & Zack, 1999; Ramadas, 2008; Sanders, Kajs, & Crawford, 2002). Instructors are encouraged to master skills in the use of multiple e-map search functions provided by many web-based e-map providers. The current list of e-map portals includes Google Earth, a search system that simulates a bird's eye view of earth from outer space and transforms the original 2-D results of GIS searches to 3-D images that users can zoom into or out from. Google Earth makes use of GIS to create images of the entire planet in the form of 3-D maps, to perform searches for small-scale geographic images that perfectly resemble the large-scale real-world landmarks, and to present search results in the form of 3-D images. The study adopted Google Earth Free that high school students could easily download from the website. The free trial of Google Earth provides different levels of satellite imagery all over the world. The satellite imagery is up to 0.61 m resolution for some urban areas. Most general users find it an ideal platform because they can access to a huge amount of resources and data.

For this project we used GIS features to design a search task, which is a basic step of collecting spatial information from Internet to prepare for spatial enquiry, to examine how landmark knowledge is produced through the type of learning environment that Google Earth offers. To successfully complete search of the given famous landmarks when only the names of the landmarks were provided, one must have rich knowledge of global landmarks—knowing at which place(s) the landmark might be. Some landmarks might be learned through the textbooks and geography instructions; while others might be gained from real life experiences by viewing the landmarks or walking in/surrounding by them. Personal environmental experiences are processed and stored through the function named as large scale environmental cognition (Evans, 1980; Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). Landmark searches involve internal representations of correct spatial information, a cognitive function referred to as spatial ability by Linn and Petersen (1985). If a landmark does not appear at a predicted location, an individual must use a combination of reasoning, guessing, exploring, using partial correct geographical knowledge and excluding incorrect hypotheses. This type of abstract reasoning is considered a central characteristic of general intelligence. Therefore, landmark search performance is considerably affected by at least four cognitive factors, abstract reasoning ability, small scale spatial abilities, large scale environmental cognition and prior knowledge about the landmark.

The technology is exciting, but educators in Taiwanese junior high schools are only starting to experiment with and discover how to use Google Earth to replace tradition memorization approaches to teaching geography, earth science, and history concepts with constructivist-based active learning and hands-on experiences (Duffy & Jonassen, 1992; Mayer & Moreno, 2002; Roth & Roychoudhury, 1992; von Glasersfeld, 1989). Constructivist theory encourages teachers to act as facilitators of active processes in which students discover principles, concepts, and facts for themselves (Di Vesta, 1987). Accordingly, teachers who engage in promoting spatial enquiry may ask students to use GIS-based search functions to search for countries, cities, and landmarks, to observe borders between countries and to use such information to contemplate national and regional economic development, international relations, population growth, and cultural issues. In this paper our focus was on the study of geographical landmark search as supported by the Google Earth search function. Our specific study goals were to observe how classroom teachers could apply this innovative technology and how students' capacities influenced their learning through Google Earth search. Google Earth allows users to key in addresses (for a limited number of countries) or coordinates to browse locations. What users have to do would be typing-in the location names (keywords) and then the system will automatically perform landmark search tasks. It is mainly image search through semantic completion and users are not required to use their spatial ability or geographical knowledge; they simply do not have to put mind in. We purposefully disabled this function—as well as the layers, places, and search panels—in order to stimulate image search behaviors and avoid the interference of using semantic search strategy in image search task. In other words, participants did not have access to keyword searches, but were required to use the mouse and the zoom-in and zoom-out features for navigation.

In sum, our purpose for this research was to investigate connections between individual differences in cognitive skills and performing e-map searches. Our research design is illustrated in Fig. 1.

2. Research questions

1. How well do junior high school students perform landmark searches using Google Earth?
2. Do statistically significant correlations exist between landmark searches and the following factors: mental rotation, abstract reasoning, environmental cognition (landmark representation, intersection representation, and frame of reference), and prior geography knowledge?
3. What is the order of predictive power among mental rotation, abstract reasoning, landmark representation, intersection representation, frame of reference, and prior geography knowledge regarding the ability to successfully perform landmark searches using Google Earth?

3. Literature review

Thorndyke and Hayes-Roth (1982) are among researchers who have demonstrated considerable differences in the ability of individuals to acquire spatial knowledge from maps. Factors that affect this ability range from cognitive aspect (e.g., abilities, cognitive strategies, domain knowledge), affective aspect (e.g., personality, cognitive dispositions), to demographical/background aspect (e.g., gender, age, SES) (Egan, 1988).

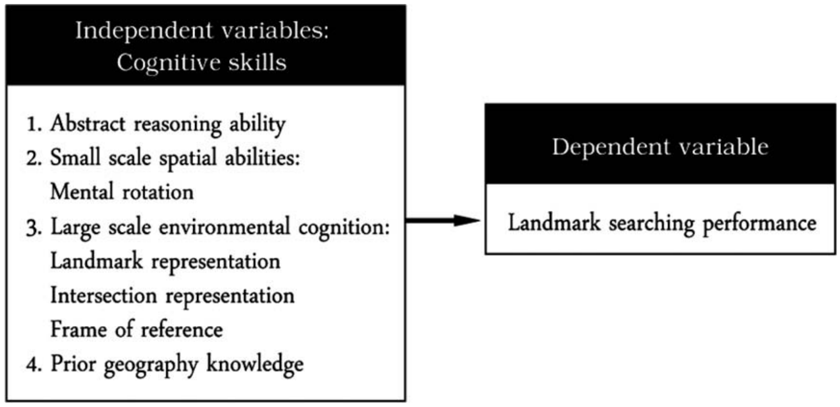

Fig. 1. Main study design.

3.1. Spatial ability

In this paper we abided by Reber's (1985) broad description of spatial abilities as cognitive functions that support human mental rotation, visual spatial tasks, and object orientation in space. In their meta-analysis of related studies published between 1974 and 1982, Linn and Petersen (1985) found three categories of spatial tests: spatial perception (the ability to determine mental rotation in spite of distracting information), spatial visualization (the ability to manipulate complex spatial information when several stages are needed to produce a correct solution), and mental rotation (the ability to mentally rotate 2D or 3D imagery without the assistance of external tools). However, challenges arise when a factor analytical approach is used to group and define spatial abilities, the most important being that doing so does not necessarily produce converging definitions. The lack of a universally accepted definition of spatial ability may also be explained by the variety of psychometric tests used to analyze the term, as well as the lack of reliability of factor structures produced by multiple tests (Voyer, Voyer, & Bryden, 1995).

Psychometric approaches frequently entail the use of such tasks as the mental rotation of shapes, solving mazes, and finding hidden figures to measure spatial abilities (Carroll, 1993; Eliot & Smith, 1983; Lohman, 1979; McGee, 1979)—in other words, imagining the manipulation of visual forms in small-scale spaces relative to the body rather than the individual's own changing location and orientation in large-scale spaces. Mental rotation is very likely to be correlated with required cognitive functions for manipulating GIS-based tools such as Google Earth (e.g., performing landmark searches and finding/reading maps). These functions include the construction of internal representations of global and geographic information, maintaining high-quality internal representations, and performing spatial transformations to make inferences. Users may orient, reposition, and rotate internal representations before and as they spin a globe on a monitor, zoom in or out from an image, or otherwise use their cursors to manipulate globes or e-maps.

Correctly searching for landmarks with the help of a GIS tool also requires abstract reasoning, a non-verbal reasoning ability that is highly correlated with general ability (Pellegrino & Hunt, 1991). When searching for landmarks, users must form hypotheses, make explorations, and make reasonable guesses based on limited information. In this study, we assumed that performing searches with help of a GIS tool is dependent on both mental rotation and abstract reasoning capabilities.

3.2. Environmental cognition

Examples of everyday tasks requiring environmental cognition are finding one's way between two points and learning the layout of a building or city (Evans, 1980). Environmental space is large in scale relative to the body; individuals are said to be contained within such space. According to Siegel and White (1975), environmental cognition is developed in three phases: (a) landmark recognition; (b) constructing access to route knowledge, during which routes between landmarks and path intersections are established, eventually forming clusters that are linked to each other via topological relationships; and (c) developing coordinated frames of reference within and across clusters, thereby forming survey knowledge.

Hart and Moore (1973) used Piaget's studies of perspective taking to study spatial orientation in children, and traced the gradual development of increasingly accurate and complex spatial relationship memories of real environments. According to Hart and Moore, the frame of reference aspect of spatial relationships also has three developmental stages. In the first, egocentric orientation frame of reference, young children organize objects spatially primarily in terms of personal mobility experiences—in other words, they orient all objects in their environment to their own central position and disregard rotation. The second, fixed frame of reference, occurs during early concrete operational stages, when children move away from egocentric orientation and toward the fixed location of a specific object, usually one that they are most familiar with. Rotation is comprehended, but children in this phase still have difficulty coordinating multiple referents. In the third, or coordinated frame of reference, children are capable of perceiving all possible routes to the locations of known objects. Locations are no longer oriented in terms of relationships to their body positions in space or the relationships among proximate landmarks, but in respect to broader areas and expressed using abstract cardinal directions.

Assessing environmental cognition include recognizing scenes from a learned environment, retracing previously taken routes, estimating route distance, pointing to non-visible landmarks, and sketching real-world maps (Evans, 1980; Liben, Patterson, & Newcombe, 1981; Spencer, Blades, & Morsley, 1989). When geologists study relationships between the environment and human beings, they often utilize map sketches to show how human beings absorb, organize, save, memorize, and handle spatial knowledge and concepts (Downs & Stea, 1977; Golledge & Stimson, 1987; Ouyang, 1981). Consequently, cognitive maps are viewed as tools for understanding cognitive processes involved in the acquisition, representation, and processing of information about actual environments (Best, 1989; Golledge, 1999; Shih & Su, 1992; Thomas & Willinsky, 1999; Tverksy, 2004).

For this study, participants were asked to create cognitive maps of their school neighborhood; we analyzed their maps in terms of landmark representation, path intersection representation, and frame of reference, testing our hypothesis that these three indicators of environmental cognition are all significantly correlated with landmark searches via the GIS-based Google Earth. Since the search task specifically requires the use of three cognitive functions (positioning, rotating, and orienting within a movable e-map/global screen) to locate landmarks, search outcomes were assumed to be dependent on path intersection representation, frame of reference quality and landmark representation quantity.

3.3. Prior knowledge

Prior knowledge holds a central position in the three most influential learning theories of the past half-century: schema (Anderson, 1977), mental models (Johnson-Laird, 1983), and constructivism (Roth & Roychoudhury, 1992; Von Glasersfeld, 1989). From misconception research, there is a common agreement that learners construct concepts from prior knowledge (Novak, 1990). Previous research also used expert-novice comparison paradigm to reveal the impact of science prior knowledge on learning process and resulting knowledge structure. Chi, Feltovich, and Glaser (1981), for example, found that experts have extensive domain knowledge and are more able to attend and remember the core principles represented by a graphic. In other words, they concentrate more on the relevant parts of incoming messages for the construction of a coherent schema or effective mental model. Though many of previous misconception and novice-expert studies focused on the domains of Physics and Chemistry, their findings are applicable to geographic learning. Various usages of visual representations by experts and novices can be attributed to different size of prior knowledge and different coherent degree of how prior knowledge stored in cognitive structure (Cook, 2006). Information-processing theorists suggest that people have a limited working memory, and when working memory is overloaded, learning does not happen. Prior knowledge largely determines the limitation for working memory. Currently, mixed results have emerged from empirical studies of the effects of prior knowledge on various learning outcomes (comprehension or problem solving) in several domains including geography (see, for example, Dochy, Segers, & Buehl, 1999; Hoz, Bowman, & Kozminsky, 2001; O'Reilly and McNamara, 2007).

In this study we used grades in previous geography classes as the primary indicator of prior knowledge, acknowledging that such grades reflect success in the passive learning (memorization) of geography facts. Therefore, landmark searches as the outcome of active construction is somehow correlated with prior knowledge and we also assumed that prior knowledge learned through passive manner is a less successful predictor compared with mental rotation and environmental cognition.

4. Methodology

4.1. Participants

Study participants were 153 seventh graders (73 boys, 80 girls) from a junior high school located in central Taiwan. According to prior performance records for the national senior high school entrance examination, the school population was well below the top 15% of all junior high schools in Taiwan. The sample consisted of student from five classes that were randomly chosen from the school's 21 classes. In Taiwan, the government stipulated junior high school students must attend schools in their neighborhood school district. If adolescent population outnumbers student size that all schools in a district can take in, they have to queue in the descent order of the years their family live in the school district. For the participants, the average number of years living in this school district was 10.23 (SD = 4.26, range from 3.93 to 14); this number suggests that all participants lived more than 3 years in this school district and we assume they are familiar with the neighborhood enough to sketch a map of the school district as a required of this study. All students in the sample were familiar with basic computer applications but had never used the Google Earth website.

4.2. Measures

4.2.1. Mental rotation

Our mental rotation measure was adopted from Lu, Ou, and Lu's (1994) Multiple Dimension Aptitude Test Battery (MDATB), a commonly used standardized aptitude test in Taiwan that consists of eight subscales. Test reliability and validity were acceptable according to its manual and the norms were developed for junior high school and high school students. In the subtest of mental rotation, participants are presented a target figure and four test figures, and are instructed to select the test figure that best represents a rotation of the target figure. Participants were given 6 min to respond to 32 items.

The reliability and validity of MDTB was provided by Lu et al.'s (1994). For the mental rotation scale, they found the internal consistency coefficient (Cronbach's alpha) in a sample of ninth grade boys was .80 and in eleventh grade girls .76; the test-retest reliability in a sample of ninth grade boys was .68, in tenth grade boys .80, in tenth grade girls .70. The concurrent validity for mental rotation scale was found between MDATB and a previous well established Differential Aptitude Test (Lu, Gien, & Chen, 1988) for tenth grade boys ($r = .58$, $p < .01$).

4.2.2. Abstract reasoning

Our abstract (non-verbal) reasoning measure was also adopted from the MDATB. Each item consists of five figures that form a series with a specific embedded logic. Participants are required to select from another set of four figures the one best representing the subsequent item in the series. Participants were given 15 min to complete this 32-item scale. For, the reliability test, Lu et al.'s (1994) found the internal consistency coefficient in a sample of ninth grade boys was .82 and in eleventh grade girls .73. The test-retest reliability in ninth grade boys was .70, in tenth grade boys .83, and in tenth graders students .62. An acceptable concurrent validity was found between MDATB and DAT in tenth grade boys ($r = .37$, $p < .01$).

4.2.3. Map sketch

We used map drawings of a familiar real world setting as our environmental cognition measure. Participants were asked to sketch maps of the area immediately surrounding their junior high school. No restrictions were placed on the area to be covered in their maps, but they were required to include streets and facilities (e.g., stores, buildings, parks, and open spaces) and to place them accurately.

Using the modified system described by Ouyang (1982), Matthews (1984), and Su and Huang (2005), sketch maps were scored based on the three above-mentioned environmental cognition features, landmark representation quantity, intersection representation quality, and frame of reference quality. Higher scores represented more sophisticated knowledge of spatial layout—that is, correct and precise positioning of landmarks, correct alignment of streets, and proper coordination of map elements according to a clear frame of reference.

Our landmark representation scoring procedure is to count the number of identifiable objects in a sketched map. The purpose for this scoring item is to evaluate whether participants observe and pay attention to any objects around their school and how many objects they can save and memorize in their mind. The importance

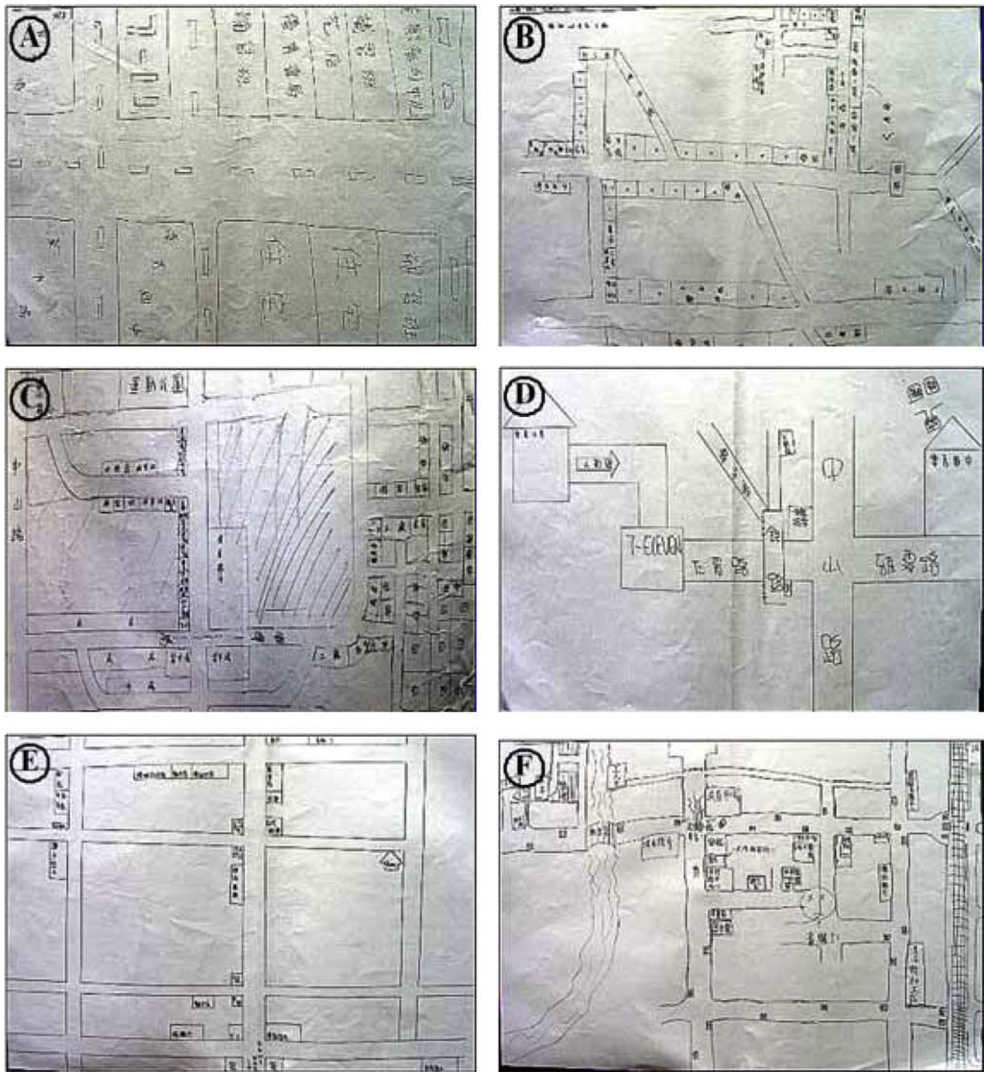

Fig. 2. Some exemplifications of sketch maps. ((A) orthogonal intersections; (B) orthogonal and oblique intersections; (C) orthogonal, oblique, and curved intersections; (D) egocentric frame of reference; (E) fixed frame of reference; (F) coordinated frame of reference).

of all objects is the same, therefore every tangible object (e.g., streets and facilities) or each intangible indicator of geographic directions or traffic flow in a map gains one point.

Our intersection representation scoring procedure focuses on path intersection pattern quality. We identified three types of intersections described by Ouyang (1982): (a) orthogonal intersections (Fig. 2, map A) with a majority of paths in perpendicular positions, considered the lowest quality; (b) orthogonal and oblique intersections (map B); and (c) orthogonal, oblique, and curved intersections (map C) representing precise and flexible combinations of all intersections pattern types, which are considered higher quality.

Our frame of reference scoring procedure is based on Hart and Moore's (1973) categories. In maps reflecting an egocentric frame of reference (Fig. 2, map D), scenes and paths are centered solely on the participants' standing perspective; anything outside of the participant's physical view is excluded. These maps often show less elaborated manner containing merely self-relevant landmarks such as the student's home, school, or route between the two points. Wrong locations of landmarks are common. These self-centered maps were viewed as representative of lower spatial capabilities. Fixed frame of reference maps (map E) contained fixed positions or landmarks that serve as centers for all scenes and paths. In coordinated frame of reference maps (map F), all scenes and paths are aligned in an abstract and coordinated fashion, and identifiable landmarks are located in correct positions and with accurate orientations.

Two teachers from the junior high school used in this study devised a scheme for scoring the quality of intersection representation and frame of reference, then separately rated all 153 maps. A Kappa coefficient of agreement was used to examine consistency between the two raters. Results for two quality indicators of environmental cognition indicated high inter-rater reliability for intersection representation ($K = .75$, $p < .001$) and frame of reference ($K = .60$, $p < .001$).

Scoring results for landmark representation, intersection representation, and frame of reference are shown in Table 1. The average number of illustrated objects in the student maps was 26. More than one-half of the participants (80 or 52.3%) sketched simple orthogonal intersections. Just under one-quarter (34 or 22.2%) illustrated both orthogonal and oblique intersections, and the rest (39 or 25.5%) displayed flexible patterns of orthogonal, oblique, and curved intersections. In terms of frame of reference, just over one-third (55 or 35.9%) drew egocentric maps, less that one-third (45 or 29.4%) drew fixed frame maps, and the rest (53 or 34.6%) drew high-quality coordinated frame of reference maps, which are considered appropriate to the developmental stage of this age group.

Table 1
Descriptive statistics of mental rotation, abstract reasoning, prior knowledge, landmark search and environmental cognition.

Variables	*n*	M	SD	%
Mental rotation	153	22.29	5.064	–
Abstract reasoning	153	22.01	6.156	–
Prior knowledge	153	76.53	15.50	–
Landmark search	153	41.20	13.19	–
Environmental cognition: landmark representation	153	26.61	15.20	–
Environmental cognition				
Intersection representation				
Simple orthogonal	80	–	–	52.3
Orthogonal and oblique	34	–	–	22.2
Flexible patterns of orthogonal, oblique, and curved	39	–	–	25.5
Frame of reference				
Ego centric	55	–	–	35.9
Fixed	45	–	–	29.4
Coordinated	53	–	–	34.6

4.2.4. Related functionality of Google Earth

Google Earth adopts many pictures of common areas, aerial photos that have received permission, pictures of KeyHole spy satellite and many other pictures of towns and cities via satellite (Wikipedia, retrieved December 7, 2008). Type in keywords of the landmarks you are looking for then Google Earth takes you up to the air as if you are watching the landmarks from a helicopter (Butler, 2006). Google Earth also allows image search. It adds zoom in/out function to GIS, transforming the originally 2-D searching platform to 3-D. It provides not only free of charge information regarding 3-D aerial photos but also integrates a lot of geographical data, such as data of streets, hotels, restaurants, well-renowned landmarks, routes, borders, and time related to the destination completely and accurately (Butler, 2006; Trimbath, 2006).

Our decision to use Google Earth Free was based on its features, which were considered adequate for the purposes of the study and for the needs of the participating teachers and students. As shown in Fig. 3, the Google Earth interface consists of (a) a 3D Viewer for viewing global and terrain images (Fig. 3, circle 1); (b) a sidebar for overlaying landmarks, polygons, paths, and images (circle 2); (c) navigation controls, including tilting, zooming and pulling out, and moving around within an image (circle 3); (d) a layers panel to display points of interest (circle 4); (e) a places panel to locate, save, organize, and revisit landmarks (circle 5); (f) a search panel to find places and directions and to manage search results (circle 6) (Google Earth, retrieved December 7, 2008).

The term "layers" refers to the high or low resolution of system landmarks. For example, Mississippi River contours have lower resolution (upper layers on an e-map) than the Statue of Liberty. We divided landmark layers into seven levels according to degree of resolution: Level 1 shows the entire globe (lowest resolution); Level 2 continents and oceans; Level 3 countries; Level 4 capitals, cities and counties; Level 5 villages, towns, mountains, and rivers; Level 6 streets; and Level 7 buildings (highest resolution). The landmarks that the study participants searched for had various levels; the zoom-in zoom-out feature allowed for adjustments to be made to resolution levels.

Google Earth allows users to key in addresses (for a limited number of countries) or coordinates to browse locations. We purposefully disabled this function—as well as the layers, places, and search panels (circle 4, 5, and 6 in Fig. 3)—in order to emphasize image-searching behaviors among the students. In other words, participants did not have access to keyword searches, but were required to use the zoom-in and zoom-out features for navigation.

4.2.5. Landmark searches

Students were instructed to complete "landmark search worksheets," each containing the same 16 search tasks selected by three geography teachers. Landmark resolution levels ranged from 1 to 6, with at least two tasks for each level—one for a familiar landmark and another for an unfamiliar location as determined by the three experienced teachers. For example, at level 3 the familiar-to-unfamiliar tasks were "Taiwan Island" and "Madagascar Island." The four level 7 tasks were the Taipei 101 building (the tallest inhabited building in the world, judged as familiar), the participants' school

Fig. 3. The user interface of Google Earth.

(familiar), the Statue of Liberty in the United States (relatively unfamiliar), and the US Pentagon (unfamiliar). The description of each task included a printed landmark illustration and a short description. Students were given 50 min to complete the 16 search tasks and to upload pictures that they found during the session.

Students were given a maximum of 5 points for each correct uploaded picture that was identical in direction, distance, and level to the corresponding illustration on the worksheet, for a maximum score of 80. Fewer points were awarded for pictures that did not precisely match the illustration. For example, 5 points were awarded for a picture of the Taipei 101 building that had the same level 7 and orientation as the illustration, 4 points if the building direction or angle was different, 3 points if the picture was of Taipei City but not the building, 2 points for downloading a picture of Taiwan Island, and 1 point for downloading a picture of Asia. No points were awarded for pictures of other continents or if a student could not find a picture.

Landmark search results were scored by the three independent raters. A Kendall's coefficient of concordance was used to examine consistency among the three coders; our results indicated a high level of inter-rater reliability ($W = .98$, $p < .001$).

4.3. Procedure

The study was conducted over four weeks (1 h per week). Mental rotation and abstract reasoning data were collected during week 1, maps of the school and surrounding community were drawn and collected during week 2, Google Earth features and methods were taught during week 3, and the search tasks were completed during a 50-min session in week 4.

5. Results

5.1. Descriptive statistics

Our data indicate that the large majority of the study participants successfully learned how to find images using the GIS-based Google Earth, but the success rate for completing search tasks decreased as the required resolution level increased. For example, in the unfamiliar landmark category, the number of students earning between 1 and 5 points was 152 for locating the African continent (level 2), 143 for Madagascar Island (level 3), 118 for Tokyo (level 4), 58 for Fuji Mountain (level 5), 51 for Athens Olympic Stadium (level 6), and 44 for the Statue of Liberty (level 7). The author also observed that for those who could complete the searching tasks, they could control and operate the Google Earth searching system. That is, it is impossible to find the target landmarks accidentally.

Our results suggest that prior knowledge accounted for a considerable amount of success in landmark search performance. Participants earned considerably higher scores on searches for Taiwan Island, Yu Shan Mountain (Taiwan's tallest), Wuchi Port (a commercial port near the participants' home city), the Taipei 101 Building, and their junior high school than the unfamiliar landmarks in the same level. For example, the numbers of students earning between 1 and 5 points for the Taipei 101 Building (familiar), their school (familiar), the Statue of Liberty (unfamiliar), and the Pentagon (very unfamiliar) (all level 7) were 93, 60, 44, and 13, respectively. In sum, more students successfully searched the target landmarks if they were familiar with the landmarks.

5.2. Correlations

5.2.1. Spatial abilities with environmental cognition

Results for data pertaining to the second research question are shown in Table 2. A statistically significant correlation was found between mental rotation and abstract reasoning ($r = .351$, $p < .01$); a possible explanation for this result is consistency in test item format in terms of information processing of small-scale figures. No correlation was found between small-scale spatial abilities and well-learned large-scale environment indicators, which conflicts with Evans' (1980) description of a conceptual association between mental rotation and the qualitative development of frame of reference. In addition, this finding is only partly in agreement with Hegarty et al.'s (2006) observations for a group of American college students that measures of small scale spatial abilities have weak or no correlations with information processing measures of newly learned environmental settings. Finally, low correlations were found between landmark representation and intersection representation ($r = .391$, $p < .01$), landmark representation and frame of reference ($r = .275$, $p < .01$), and medium correlations was found between intersection representation and frame of reference ($r = .685$, $p < .01$).

5.2.2. Spatial abilities and environmental cognition with prior knowledge

A statistically significant correlation was found between abstract reasoning ability and prior geographic knowledge ($r = .302$, $p < .01$), but not between mental rotation ability and prior geographic knowledge. This suggests that learning geography is dependent on general intelligence but not on the ability to mentally rotate spatial representations. We also found a statistically significant correlation between landmark representation (an indicator of less complex spatial memory) and prior geographic knowledge ($r = .176$, $p < .05$), but not between prior geographic knowledge and two indicators of more complex environmental information processing—intersection representation and frame of reference. This strongly suggests that conceptual understanding accounts more about the outcomes of ordinary geographical learning than transformations of complex spatial information, which is more closely associated with hands-on experiences and knowledge construction.

Table 2
The coefficient of correlation of mental rotation, abstract reasoning, environmental cognition, prior knowledge and landmark searching.

Test items	Mental rotation	Abstract reasoning	Landmark representation	Intersection representation	Frame of reference	Prior knowledge	Landmark searching
Abstract reasoning	.351**	1					
Landmark representation	.004	.069	1				
Intersection representation	.122	.043	.391**	1			
Frame of reference	.081	.093	.275**	.685**	1		
Prior knowledge	.131	.302**	.176*	.116	.056	1	
Landmark searching	.293**	.256**	.354**	.500**	.367**	.260**	1

* $p < .05$.
** $p < .01$.

Table 3
Regression analysis summary for mental rotation, abstract reasoning, environmental cognition, and prior knowledge predicting students' searching score.

Predictor variables	R	ΔR^2	ΔF	B	β	t
Step 1	.509	.259	52.708***			
Frame of reference				7.959	.509	7.260***
Step 2	.563	.059	12.914***			
Frame of reference				7.568	.484	7.132***
Mental rotation				.635	.244	3.594***
Step 3	.593	.034	7.808***			
Frame of reference				6.379	.408	5.688***
Mental rotation				.635	.251	3.778***
Landmark representation				.173	.199	2.794**
Step 4	.613	.025	5.822***			
Frame of reference				6.272	.401	5.678***
Mental rotation				.6	.23	3.499**
Landmark representation				.151	.174	2.445*
Prior knowledge				.137	.161	2.413*

* $p < .05$.
** $p < .01$.
*** $p < .001$.

5.3. Predictive effects of five factors on landmark searching

We used a multiple regression analysis (stepwise method) to clarify the relative predictive powers of mental rotation, abstract reasoning, environmental cognition, and prior knowledge on successful landmark searches using Google Earth (Table 3). According to our results, a four-factor model accounted for 60% of the variance for landmark searches ($R^2 = .613$, $F = 22.298$, $p < .001$). The strongest predictor was frame of reference (beta = .401, $t = 5.678$, $p < .001$), followed by mental rotation (beta = .230, $t = 3.499$, $p < .01$), landmark representation (beta = .174, $t = 2.445$, $p < .05$), and prior geographic knowledge (beta = .161, $t = 2.413$, $p < .05$). Abstract reasoning ability and intersection representation did not account for landmark searches using Google Earth. Instead, success was more likely for students (a) with an advanced coordinated frame of reference, (b) with greater capacities for mental rotation, (c) who were more capable of sustaining real-life landmark knowledge in the form of spatial memory, and (d) who had acquired greater amounts of prior geographic knowledge.

6. Discussion and implications

This study shows the results of several Taiwan teachers actively introducing new technology into their geography classes. In accordance with many students' perception that geography can be learned passively, evidences of this study confirm that geography grade is accounted for by abstract reasoning ability (general intelligence) and landmark representation (acquiring basic spatial information). Conceptual understanding seems gained much more emphasis in the previous geography examinations in Taiwan junior high schools.

The first result suggests that Google Earth landmark searches require complex cognitive processing in the form of conceptual understanding (landmark representations and prior geographic knowledge) processed by long term memory and spatial representation processing (using coordinated reference frames and mental rotation) controlled by working memory. Google Earth and other comparable tools can be used in such a manner as to support constructivist teacher activities—engaging students as they complete activities and posing questions to promote reasoning (DeVries, Zan, Hildebrandt, Edmiaston, & Sales, 2002). In order to fully engage and challenge learners, learning tasks must reflect the complexity of learning environments in a manner that gives them ownership of the learning process, problem-solving process, and of the problem itself (Derry, 1999). Our results indicate that Google Earth can facilitate this kind of learning in geography classrooms.

Another study contribution is its replication of previous findings showing weak or no correlations between small-scale spatial abilities and large-scale environmental cognition (Hegarty et al., 2006). Both small-scale spatial abilities and large-scale environmental cognition are important factors of individual differences in knowledge construction of geography.

According to Shih and Su (1992) and Lay (1999), the ways that students use maps are affected by their cognitive development, thus the ability to use maps is representative of an individual's spatial cognition. We think that spatial cognition is developed by exploring in spatial environment. In landmark searching process, the recognition of all roads, buildings, and landforms, differentiating directions, proportion, distance, area, location, and sequence are closely related to environmental cognition. The use of Google Earth search system is similar to the encoding and saving of information in real environment. Therefore, people with better environmental cognition are better at manipulating software to find out landmarks.

Spatial ability refers to the ability to imagine object moving in the three-dimensional space or to manipulate the object imaginatively. People with better spatial ability could twist, transfer, or rotate the image to a new location in their brains. They are able to imagine the rotation of objects in their minds, the floor plan of objects on a flat surface or the folded three-D. They also have the ability to understand the change of objects' location in the space. Therefore, people with better spatial ability can imagine the differences between the simulated environments and authentic situations.

However, the predictor of geographical knowledge was not as good as previous expectations. For example, whereas most Taiwanese junior high students know that the Statue of Liberty is in New York, only a small number of participants in this study were capable of using Google Earth to locate the United States, the East coast of North America, the New York State, and the Liberty Island in New York Harbor step by step. The GIS-based tool required students to use prior knowledge or their reasoning skills to locate all of these landmarks. Accordingly, geographical knowledge did not remarkably affect the effectiveness of searching tasks.

GIS has been suggested as a supportive tool to develop students' spatial thinking and enquiry which is, in turn, an important competence underpinning a lot of science discoveries. In using GIS to search images, individual must process verbal and pictorial information simultaneously. Users have to read written information about what they need to search and process pictorial information including the static pictures, the dynamic transformations of static pictures to animation and the rotating animations that simulate globe function. Mayer's cognitive theory of multimedia learning (CTML, Mayer, 2005; Mayer & Johnson, 2008) demonstrates that processing descriptive information (words) and depicted information (pictures/animations) results in two mental models, a "verbal mental model" and a "visual mental model." In both channels, information is processed independently until the two mental models are established. Learners are active constructors of knowledge; they actively select, combine and organize relevant visual and verbal information. Under some conditions learners learn better when they are able to hold corresponding visual and verbal representations in working memory at the same time. One major factor mediating the cognitive capacity of a learner is prior domain knowledge. Learners use working memory capacity in a more effective manner when they have already possessed plenty prior knowledge (Kayuga, Ayres, Chandler, & Sweller, 2003; Mayer, 2001). Another important aspect is spatial ability (Huk, 2006). It is reasonable to consider similar factors that affect multimedia learning also affect search of e-map supported by GIS because

GIS incorporate complex information as it is in multimedia learning materials. Therefore, for involving spatial representation tools in instruction, teachers need to consider design principles of instructional multimedia materials (Mayer, Steinhoff, Bower, & Mars, 1995) and cognitive load on how complex information negatively affects learning and the ways to alleviate learners' working memory load (Paas, Renkl, & Sweller, 2004; Sweller, 1988, 2005).

In sum, our results indicate that a surprisingly large percentage of participants were in a spatial cognition developmental stage marked by an egocentric orientation frame of reference, explaining they had not enough skills in the creation and use of maps. However, we also found that visual stimuli promoted learner interest and attention, and supported learner efforts to construct new knowledge and facilitate memory. This suggests (a) the learning of geographic knowledge among Taiwanese junior high school students can benefit greatly from direct exposure to either actual or virtual environments, and (b) presenting concepts such as distributional relationships among spatial phenomena in an active and vivid manner can enhance student interest in learning geography. It is our hope that this study will support the expanded use of 3D simulation software and GIS-based tools such as Google Earth in Taiwanese classrooms.

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