EFFECT OF GIS LEARNING ON SPATIAL ABILITY

A Dissertation

by

JONG WON LEE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2005

Major Subject: Geography

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ABSTRACT

Effect of GIS Learning on Spatial Ability. (May 2005)

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This research used a spatial skills test and cognitive-mapping test to examine the effect of GIS learning on the spatial ability and spatial problem solving of college students. A total of 80 participants, undergraduate students at Texas A&M University, completed pre- and post- spatial skills tests administered during the 2003 fall semester. Analysis of changes in the students' test scores revealed that GIS learning could help students improve their spatial ability. Strong correlations existed between the participants' spatial ability and their performance in the GIS course. The research also found that spatial ability improvement linked to GIS learning was not significantly related to differences in gender or to academic major (geography majors vs. science and engineering majors).

A total of 64 participants, recruited from students enrolled in Introduction to GIS and Computer Cartography at Texas A&M University, completed pre- and post- cognitive-mapping tests administered during the 2003 fall semester. Students' performance on the cognitive-mapping test was used to measure their spatial problem solving. The study assumed that the analysis of the individual map-drawing strategies would reveal information about the cognitive processes participants used to solve their spatial tasks. The participants were requested to draw a map that could help their best friends find their way to three nearby commercial locations. The map-drawing process was videotaped in order to allow the researcher to classify subjects' map-drawing strategies. The study identified two distinctive map-drawing strategies: hierarchical and regional. Strategies were classified as hierarchical when subjects began by drawing the main road network across the entire map, and as regional when they completed mapping sub-areas before moving on to another sub-area. After completion of a GIS course, a significant number of participants (about half) changed their map-drawing strategies. However, more research is necessary to address why these changes in strategy came about.

DEDICATION

To my loving wife Jong Ok

You are my rock, you are my love.

ACKNOWLEDGEMENTS

I would like to acknowledge all the people who have helped me to complete the work for this degree. I am most grateful for the guidance I received from each of my committee members: Dr. Robert Bednarz, Dr. Sarah Bednarz, Dr. Hongxing Liu, and Dr. Lynn Burlbaw. Their support and expertise were essential in the progress and completion of my dissertation study.

Special thanks go to Drs. Robert Bednarz and Sarah Bednarz who served as co-chairs of my dissertation committee. Thank you, Bob, for serving as my mentor since we met for the first time in 2000 at Seoul. You have always been there to respond quickly to my questions and to provide advice into what I needed to do. And thank you, Sarah, for always being such a positive person and for all of your support while I studied in College Station. Your encouragement and caring attitude have helped me immeasurably to attain my ultimate goal.

I extend a special thanks to Dr. Anthony Filippi, Dr. Andrew Klein, Dr. Daniel Sui, Dr. So-min Cheong, Dr. Douglas Sherman, Matthew Clemonds, Alexis Green, and Jeatawn Degelia for their assistance in data collection.

I would also like to thank my friends and colleagues Dr. Gillian Acheson, Sandra Metoyer, and Jose Gavinha for reviewing my manuscripts and providing valuable advice. To Jose, your input has been influential in the “finishing” of this dissertation.

Last but not least, I would like to express my sincere gratitude to my wife and best friend, Jong Ok, for all her encouragement to pursue this degree and her endless patience and support throughout the process. Your love and strength are limitless and I am cherishing every moment in the journey we travel together. Also, I would like to thank my daughter Soyoon, your smiles and babbles have lightened my life the past two years and gave me the ultimate push to finish my work.

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CHAPTER I

INTRODUCTION

Context of Research Problem

This study investigates the effects of GIS learning on spatial abilities and spatial problem solving of college students. It has been suggested that GIS can help students develop spatial abilities (Albert and Golledge 1999; Self et al. 1992), solve spatial problems (Audet and Abegg 1996; Audet et al. 1993; Audet and Paris 1997; Baker 2000; Barstow 1994; Hall-Wallace and McAuliffe 2002; Kerski 2000; Salinger 1995; Wigglesworth 2000), reason spatially (ESRI 1996; Geography Education Standards Project 1994; Hagevik 2003; UCGIS 1997), improve higher-order thinking skills (Ramirez 1995a; Sanders et al. 2001; West 2003), enhance map-reading skills (Forer and Unwin 1999), and learn geographic principles (Patterson et al. 2003).

Despite many claims that learning GIS improves spatial abilities, results are inconsistent concerning both the existence and magnitude of the effects of GIS learning on spatial ability. For example, Kerski (2000) reported that high school students using GIS scored significantly higher than students using traditional methods on a spatial analysis test. Furthermore, the GIS group demonstrated better abilities to synthesize, identify, and describe human and physical patterns. In research examining how students' spatial abilities affect the understanding of environmental content after using GIS,

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This dissertation follows the style of *Journal of Geography*.

Hagevik (2003) concluded that learning with GIS developed students' spatial-visual thinking skills. A study by Baker (2002) concluded that students showed improvement in integrating science process skills after a two-week GIS treatment. However, GIS students in the same study did not improve their ability to recognize geographic patterns and make generalized statements about the trends in the data. This finding confirmed research by Abbott (2001), who did not find a significant difference between students in an experimental GIS group and the control group in a test of integrated scientific process skills. A study by Albert and Golledge (1999) also did not find significant differences between GIS-users and non-users in subjects' abilities to use map overlays. A brief description of major concepts used in this study follows.

GISystem and GIScience

There has been extensive debate over whether the "S" of GIS should be interpreted as system (GISystem) or science (GIScience) (Forer and Unwin 1999; Kemp et al. 1992; Longley et al. 2001; Wright et al. 1997). GISystem focuses on technology for the acquisition and management of spatial information (Forer and Unwin 1999). According to Wright et al. (1997), "doing GIS" is differentiated from "doing GISc" as follows:

> [Doing GIS] is identified as a problem solving activity, while science was linked to discovery and problem understanding … (Wright et al. 1997, 349).
>
> Doing GIS amounts to making use of a tool to advance the investigation of a problem … (Wright et al. 1997, 355).
>
> Doing GIS is not necessarily the same as "doing science" (Wright et al. 1997, 357).

Unlike GISystem, GIScience pursues a scientific approach to the fundamental issues arising from geographic information (Longley et al. 2001). In this perspective, "doing GIScience" is interpreted as follows:

> [GIScience] spoke mainly about the *use* of GIS as a method or body of knowledge for developing and testing spatial theories, not about the physical entity GIS itself … (Wright et al. 1997, 349).

> Doing GIS is "doing science" and the only sufficient grounds for legitimacy as a research field in the academy (Wright et al. 1997, 358).

Despite considerable discussion, the distinction between GISystem and GIScience is still not clear. In fact, some prefer a fuzzy distinction between GISystem and GIScience. For example, Wright et al. (1997) argue that the GIS should be described along a "fuzzy" continum rather than "black-and-white" boxes of description. According to this idea, GIS is interpreted depending on its purpose or situation. For instance, while GIS having technical and problem-solving orientation at the undergraduate level course is closer to a tool or system, GIS emphasizing discovery and problem understanding at the graduate level or for research is more likely to be science. In this study, GIS refers to both its use as a tool and technology (GISystem), and to inference and spatial reasoning (GIScience).

GIS Learning

In order to use GIS properly, three different types of knowledge are needed: declarative, procedural, and conditional knowledge:

> Declarative knowledge is "knowing that," or "knowing about." It is fact, concepts, or ideas organized in different ways, as lists, as statements, or as stories. Knowing how to do something is termed procedural knowledge. Performing a series of tasks in the correct sequence requires procedural knowledge. Much of the learning involved in GIS is procedural knowledge. The third type of knowledge is termed conditional knowledge, knowing when and why to use a procedure. All three types of knowledge are required to learn and do GIS (Bednarz 1997, 197).

GIS leaning in this study refers to learning what GIS is, how to use it, and when and where to use it. The purpose of this study is to examine whether the completion of a GIS course affects spatial abilities of college students. Therefore, “GIS learning” in this study is defined narrowly as the completion of a semester-long GIS course offered at the undergraduate level.

Spatial Ability in the Use of GIS

Cognitive psychologists, such as McGee (1979b), generally agree that spatial ability comprises several distinct but interrelated factors. Nevertheless, some disagreement still exists about whether there are two dominant dimensions–spatial visualization and spatial orientation–or whether a third–spatial relations–is also a fundamental dimension of spatial ability (Gilmartin and Patton 1984; Golledge and Stimson 1997; Lohman 1979; Montello et al. 1999). Spatial visualization is the ability to mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli. Spatial orientation involves the comprehension of the arrangement of elements within a visual stimulus pattern, the aptitude for remaining unconfused by the changing orientations in which a configuration may be presented and the ability to determine spatial relations in which the body orientation of the observer is an essential part of the problem (McGee 1979b). The dimension that is the least clearly defined, and the most contentious, is spatial relations:

> Spatial relations include abilities to recognize spatial distributions and spatial patterns, to connect locations, to associate and correlate spatially distributed phenomena, to comprehend and use spatial hierarchies, to regionalize, to orientate

> to real-world frames of reference, to imagine maps from verbal descriptions, to sketch map, to compare maps, and to overlay and dissolve maps (Golledge and Stimson 1997, 158).

Identification of spatial activities employed by using GIS is a starting point to investigate a relationship between GIS learning and spatial abilities (Bednarz 1995; Self et al. 1992). For example, it has been suggested that GIS learning is directly related to spatial abilities as follows:

> Both remote sensing and cartography require spatial-visual skills and an understanding of spatial relations. Aerial photographic interpretation involves specific abilities, including feature identification, clustering and/or grouping, and recognition of spatial association. … Users of GIS techniques have to understand concepts that are uniquely spatial, such as scale, projection, geometry and topology. Geometric understanding, as evidenced by visualization tasks such as rotation, do appear to show gender differences (Self et al. 192, 335-336).

Albert and Golledge (1999) were the first to connect GIS activities to the three dimensions of spatial abilities. According to Albert and Golledge (1999), spatial orientation and spatial visualization are important to the use of GIS because users are often required to adopt new a perspective on 2-D and 3-D representations and manipulate spatial features when using a map overlay operation for example. Spatial relations are also important in recognizing spatial patterns such as spatial distribution, association, and hierarchy. In related research, Lee and Bednarz (2004) suggested that spatial relations have a stronger relationship with GIS activities than the other two spatial factors. Fig. 1 lists important GIS activities and spatial abilities. Relationship between these two will be investigated in this research.

Identified GIS Activities

- Geometric transformation (e.g., map scale and projection)
- Modifying map features (e.g., reshape, mirror image)
- Geoprocessing (e.g., merge, clip, intersect, union)
- 2-D-3-D visual transformation
- Map orientation
- Areal photo interpretation (oblique or vertical)
- Spatial measurement
- Data management (topology)
- Geocoding (Georeferencing)
- Classifying spatial data (e.g., dot map, choropleth map)
- Searching for patterns (e.g., distribution, network, hierarchy)
- Analyzing spatial data (e.g., map algebra, Boolean overlay operation, query builder, raster calculator)
- Spatial statistics (interpolation)
- Drawing (or tracing) spatial features
- Examining spatial data

Spatial Abilities

Spatial Visualization

- Mentally manipulating, rotating, twisting, or inverting pictorially presented visual stimuli

Spatial Orientation

- Remaining unconfused by the changing orientations in which a configuration may be presented

Spatial Relations

- Recognizing spatial distributions and patterns,
- Connecting locations,
- Associating and correlating spatially distributed phenomena,
- Comprehending and using spatial hierarchies,
- Orienting to real-world frames of reference,
- Imagining maps from verbal descriptions,
- Sketching map,
- Comparing maps, and
- Overlaying and dissolving maps

Fig. 1. GIS activities and spatial abilities.

Cognitive Mapping for Spatial Problem Solving

Many researchers in environmental perception and cognition have used cognitive mapping for the study of individual differences in spatial abilities (e.g., Appleyard 1970; Golledge and Stimson 1997; Hart and Moore 1973; Lynch 1960; Moore 1973). Cognitive mapping may be defined as “the mental process through which people come to grip with and comprehend the world around them" (Downs and Stea 1977, 61). When drawing cognitive maps, people cope with spatial information, select and convert information taken from a spatial environment into an organized representation, and translate information from the large-scale space of world to the small-scale space of a piece of paper (Downs and Stea 1977; Siegel 1981). The mental process used by cognitive mappers involves spatial problem solving.

> [The cognitive mapping] process generates plans for solving specific spatial problems (Downs and Stea 1977, 68).
>
> This mapmaking requirement involves decisions about what types of information we store, how we symbolize it, how we arrange and order it, and how we attach relative value or importance to it (Downs and Stea 1977, 77).

Additionally, cognitive mapping is a good measure of spatial ability and spatial problem solving since cognitive mapping requires mappers to use most of the skills in the proposed definition of spatial relations, such as recognizing spatial distributions and patterns, connecting locations, associating spatial phenomena, comprehending spatial hierarchies, and regionalizing.

Research Questions

It is widely recognized that spatial abilities are important in the use of GIS (Mark et al. 1999; Montello et al. 1999). In addition, researchers have suggested that GIS learning can positively influence the development of spatial abilities and spatial problem solving (Albert and Golledge 1999; Audet and Abegg 1996; Audet et al. 1993; Audet and Paris 1997; Baker 2000; Barstow 1994; Hall-Wallace and McAuliffe 2002; Keriski 2000; Salinger 1995; Self et al. 1992; Wigglesworth 2000). Empirical research, however, is not sufficient to provide an understanding of where GIS learning can accomplish those goals (Hall-Wallace and McAuliffe 2002; Kerski 2000). This study investigates the relationship between GIS learning and spatial abilities by using a spatial skills test and a cognitive-mapping test. This study also aims to determine how GIS learning differs by sub-populations of students based on gender, major, and course assignment type (project vs. paper). In order to address the central research question, operational research questions were formulated:

1. Will GIS learning affect students' spatial ability?
    a. Will completion of a GIS course affect the spatial ability of college students? Will completion of a cartography course be equally effective as a GIS course?
    b. Will these effects be different for male and for female students? Will these effects differ by students' academic majors?
    c. Is there a relationship between students' spatial abilities and learning achievement in a GIS course?
2. Will GIS learning affect students' spatial problem solving?
    a. Will completion of a GIS course affect the map-drawing strategy of college students?
    b. Is there a relationship between students' map-drawing strategies and spatial ability?

Research Methods

Psychometric tests have been used extensively to assess spatial abilities especially spatial visualization and spatial orientation (e.g., Goldstein et al. 1990; Kail et al. 1979; McGlone 1981; Miller and Santoni 1986; Newcombe and Dubas 1992). "Spatial" in the psychometric tests, however, refers only to small-scale (table-top) space which is not the scale most relevant to geography. Furthermore, psychometric tests hardly assess the "spatial relations" dimension which is most closely related to GIS activities (Golledge 1993; Lee and Bednarz 2004; Self et al. 1992). Since the type of standardized tests of spatial relations that were necessary for this study did not exist, a set of new tests was developed. Two paper and pencil tests, a spatial skills test and a cognitive-mapping test, were designed to measure performance on a variety of spatial abilities.

The spatial skills test contained a total of 14 multiple-choice questions and performance exercises. It was designed to evaluate students' spatial abilities, including overlaying and dissolving a map, reading a topographic map, finding the best location based on several spatial factors, correlating spatially distributed phenomena, constructing contours based on point data, and recognizing spatial data models. A total of 80 undergraduate students at Texas A&M University completed both pre- and posttests administered during the 2003 fall semester.

The cognitive-mapping test asked participants to draw a sketch map of a familiar region. It was designed to identify students' problem-solving approach, which was measured by analysis of their map-drawing strategy. This study presumed that analysis of individuals' map-drawing strategies would reveal information about the cognitive processes subjects used to operate in their environment. The participants were recruited from students enrolled in a GIS and a cartography course at Texas A&M University during the 2003 fall semester. A total of 64 students completed both pre- and posttests administered at the beginning and end of the semester. The cognitive-mapping tests were pilot tested twice during the 2003 spring semester. By comparing pre- and posttest maps that the participants produced, changes in map-drawing strategies from pre- to posttest could be determined.

Study Significance

As a result of the rapid growth of GIS industry, the importance of education and training in GIS has never been greater (Forer and Unwin 1999; Longley et al. 1999). Research regarding the teaching and learning of GIS places most of its emphasis on discussing what should be taught in a GIS course or strategies for teaching particular concepts of GIS (Bednarz 1997). The majority of this previous research fails to provide discussion of changes in the cognitive abilities of the students. Although GIS researchers and educators have suggested that GIS learning can contribute to the development of spatial ability and the improvement of spatial problem solving, this claim has not been proven experimentally (Albert and Golledge 1999). In recent years a number of articles have been published asserting that utilizing GIS in the classroom will improve students' spatial ability and problem-solving skills. Empirical research, however, is not enough to understand where GIS learning can accomplish these aimed-for goals (Hall-Wallace and McAuliffe 2002; Kerski 2000).

The outcome of this study provides a first step toward explaining the relationship between GIS learning and the development of spatial abilities. There is little research that has tested whether individuals exposed to geographic training have greater success in understanding spatial knowledge than those who have not been exposed (Golledge 1993). Furthermore there has been little research on gender differences and GIS learning (Self et al. 1992). GIS curriculum development would benefit from the results of this research.

Even though psychometric tests have been widely used to measure spatial abilities, these tests fail to assess the spatial relations dimension, which is most closely related to GIS activities. Virtually no research has been undertaken concerning spatial relations in the area of spatial cognition, either by geographers or psychologists (Golledge 1993). This study provides an initial attempt to develop a paper-and-pencil test that can directly measure some components of spatial relations.

In addition, cognitive-mapping tests provide an alternative way to measure the rich spatial ability more related to real-world situations and problem solving. In particular, this study attempts to identify individuals' map-drawing strategies based on analysis of videotapes of students' mapping sessions and follow-up interviews conducted while students watched video clips of themselves. Later, this study introduces specific typologies concerning efficient strategies and common strategies that were used to evaluate the participants' performances (spatial problem solving).

Finally, this study sheds light on a relatively untouched issue: the relationship between spatial aptitude and spatial-strategy selection by correlating participants' spatial ability with their strategy used in the cognitive-mapping test.

Study Assumptions

1. This study assumes that individuals' spatial abilities can be measured and that the spatial skills test created for this study is valid.
2. This study assumes that subjects' mapping strategy is a valid representation of their spatial problem-solving strategy.
3. This study assumes that differences between the pre- and posttest are results of the treatment.
4. This study assumes that students enrolled in the GIS course achieved the learning objectives of the course.
5. This study assumes that subjects provide answers to interview questions that accurately represent their knowledge.

Study Limitations

1. Participants are not randomly assigned to treatment groups, thus the research can not assume that the sample is representative of a greater population and limits conclusions to the sample.
2. Since this study does not affect students' grades, students may perceive it as less relevant, and not try as hard.
3. The internal reliability of the spatial skills test is relatively low (Cronbach's alpha = .7034).

CHAPTER II

REVIEW OF LITERATURE

The main focus of this study is to analyze the effect of GIS learning on students' spatial ability and spatial problem solving. This literature review aims to provide a background and context for this research question. It is divided into four sections.

The first section explores spatial cognitive processes of GIS activities. This examination provides an answer to questions such as what insights GIS allows that other ways of learning do not (Salinger 1995), and what kinds of experiences that are unique to GIS learning. This review focuses on the analytical and visual processes of GIS. The second section reviews spatial ability in the context of GIS. This section also discusses limitations of traditional assessments of the individuals' spatial ability (e.g., psychometric tests). The third section reviews spatial problem solving in the context of GIS. Since students' spatial problem-solving strategies are measured by analysis of their map-drawing processes in a cognitive-mapping task, this section focuses on evaluation methods of individual's map-drawing strategies. The last section reviews relationships between spatial ability and (spatial problem-solving) strategy choice.

Analytical and Visual Features of GIS

Analytical Processes in GIS

Researchers have argued that GIS is different from other information processing systems because of its emphasis on spatial analysis functions (Anseline and Getis 1992;

Cowen 1988; Goodchild 1987; Maguire 1991). The term "spatial analysis" has assumed various definitions over time such as "the quantitative study of phenomena that are located in space" (Bailey and Gatrell 1995, 7), "the process to turn raw spatial data into useful spatial information" (Longley et al. 2001, 278), and "set of analytical methods which require access to both the attributes of the objects under study and to their locational information" (Goodchild 1987, 68). Researchers agree, however, that spatial data analysis plays a central role in GIS (Anselin and Getis 1992). The analytical methods in GIS include (1) measurement, (2) spatial query, and (3) spatial statistics.

Table 1 synthesizes additional information about these three analytical methods. The first method deals with measurement. Since all geographical entities of the world can be clearly demarcated and positioned within some coordinate frame of reference (Laurini and Thompson 1992), basic spatial properties such as distance, area, and slope can be measured easily. The traditional manual measurements on paper maps are more difficult to extract and less accurate when compared to the new options provided by automatic measurement using GIS (Longley et al. 2001).

The second method deals with spatial queries. Transformation and optimization are the most commonly used spatial query operations in GIS. Longley et al. (2001, 282) defined transformation and optimization as follows:

> Transformations are simple methods of spatial analysis that change datasets, combining them or comparing them to obtain a new dataset, and eventually new insights. Optimization techniques are normative in nature, designed to select ideal locations for objects given certain well-defined criteria.

Spatial query often uses Boolean algebra (e.g., AND, OR, XOR, NOT) and algebraic relationships (e.g., equal to (=), greater than (>), less than (<), greater than or equal to (>=)) on multiple layers (Chang 2002).

Table 1. Three types of spatial analytical methods of GIS.

Types		Questions can be answered
Measurement (e.g., distance, shape, area, slope, aspect, orientation)		▪ What is the area of island A? ▪ What is the orientation of the main axis of a drumlin?
Spatial query	Transformation (e.g., buffering, polygon overlay)	▪ Where is the closest gas station from museum B? ▪ How many historical sites are within 1 km from a planned road? ▪ What is the total area of land below 450 feet within the boundaries of national park C?
	Optimization (e.g., location-allocation, shortest path analysis)	▪ What places can not be reached by fire trucks in 5 minutes or less? ▪ If city C wishes to build three primary schools, which locations will minimize the trips from home to school?
Spatial statistics	Data description (e.g., histogram, scatterplots)	▪ What is the average property value for different types of land use in a selected area? ▪ What is relationship between educational attainment and average income at the census tract level?
	Geostatistical analysis (e.g., spatial interpolation, estimation, prediction)	▪ Based on sampled boreholes, what is the predicted soil distribution over an unsampled area?

The third method deals with spatial statistics. There are two types of spatial statistics available in GIS, data description and geostatistical analysis (geostatistics). Data description is useful for displaying the frequency or distribution of geographic data in the form of histograms, pie charts, or scatterplots (Longley et al. 2001). Geostatistics use statistical methods to model spatial variations in data and to predict spatial and temporal phenomena (Krivoruchko et al. 1997; Shine and Walkfield 1999). A principal founcation of geostatistics can be understood through Tobler (1979)'s "first law of geography," which states that, although all things are related, near things are more related than distant things. The greater similarity between closer values is the basis for interpolation methods (e.g., inverse distance weighing/IDW, kriging, polynomial interpolation). This technique is used to estimate data for continuous variables such as rainfall, temperature, or elevation based on a limited set of sampled figures (Longley et al. 2001).

Hall-Wallace and McAuliffe (2002) reported that investigations with GIS improve students' analytical skills including data sorting, database searching, simple calculating, and the use of statistics. Other researchers argue that GIS users must identify which layers to include in GIS operations in order to determine spatial relationships, and this process will improve their spatial reasoning (Barstow 1994; Thompson et al. 1997).

Visualization in GIS

The term "visualization" has been defined in various ways. The literature on visualization is vast, with research emerging from multiple fields including psychology, cognition, art, engineering, and science. MacEachren et al. (1992, 101) argues that:

> Visualization… is definitely not restricted to "a method of computing,"… [It is] foremost an act of cognition, a human ability to develop mental representations that allow geographers to identify patterns and to create or impose order.

More recently, the term "visualization" has been extended to include elements of computer imaging technology such as computer graphics, image processing, computer vision, geometric modeling, virtual reality, and computer-aided design (Haber and McNabb 1990; MacEachren and Ganter 1990; MacEachren et al. 1992; Visvalingam 1994).

Visualization makes scientific discovery more accessible by encoding information in ways that facilitate the search for relevant information and rules (Cheng 1996). For example, visualization can lead to faster and more effective problem solving by allowing researchers to view invisible phenomena, and by displaying phenomena in different perspectives and at different scales (Card et al. 1999; Gordin and Pea 1995; Kirby and Pazer 1990; MacEachren et al. 1992; Petch 1994; Pinker 1984).

An ability to make visible the invisible is especially useful in solving abstract problems (Goldstein 1996; Pinker 1984). Dynamic representations such as 3-D visualization and virtual reality allow people to have different types of perceptual experiences, mental instead of real, which can help them to solve problems (Höll et al. 2003). Examples of such representations could be the larger scale models of invisible molecules or of DNA chains. Different representations of the same data enable people to focus on different aspects of the problem and can enhance the understanding of spatial data (Hall-Wallace and McAuliffe 2002; Hearnshaw 1994; Muehrcke 1990; Petch 1994). In order to maximize the capacity of visualization as an educational tool, results from previous research suggested that students should be provided with opportunities to analyze, synthesize, change viewpoint and scale, and compare phenomena at multiple perspectives (Ganter 1988; MacEachren and Ganter 1990; Medyckyj-Scott 1994; Visvalingam 1994).

The characteristics of GIS visualization are similar to those of visualization in general. GIS visualization serves as a tool for visual thinking and scientific inquiry by offering dramatically different ways of looking at problems (Gordin and Pea 1995; MacEachren et al. 1992; Medyckyj-Scott 1994). First, GIS visualization promotes spatial analysis by presenting spatial data at different perspectives and resolutions (Andrienko and Andrienko 1999; Barkowsky and Freksa 1997; MacEachren 1995; Monmonier 1989). “The ability selectively to emphasize features which are pertinent to a task while suppressing less relevant information” (Medyckyj-Scott 1994, 205) allows users to compare internal patterns which may be initially quite vague or seem independent from or unrelated to one another (Baker 2000; Goodchild 1992; Hearnshaw 1994; MacEachren and Ganter 1990; Medyckyj-Scott 1994; Muehrcke 1990). For example, the interactive data classification employed by most GIS software can highlight spatial patterns by changing the number of data classes and shifting class boundaries (MacEachren 1995).

Second, GIS visualization helps users identify spatial relationships between different spatial data by opening multiple thematic layers covering the same area simultaneously (Barstow 1994; Hagevik 2003; Tinker 1992). For example, the display of wildlife locations on a vegetation map may reveal the association between the wildlife species and vegetation type (Chang 2002). Furthermore, overlayed data themes of the same area are useful to answer “what if” questions (Ramirez 1995b).

Third, GIS visualization offers various representational formats of the same spatial data including 2-D and 3-D maps, charts, graphs, tables, images, and animations. If they occurred in isolation, there would be no difference between GIS visualizations and the images produced by other information processing systems. GIS visualizations, however, can combine graphs, charts, and tables with their display in maps. A higher level of understanding can be acquired by examining various permutations of maps, tables, and graphs (Egenhofer and Kuhn 1999; Muehrcke 1990; Wiegand 2003).

Finally, 3-D techniques for visualization and animation that can simulate spatial reality allow viewers to recognize and understand spatial relationships more quickly (Abler 1987). In GIS, for example, a 2-D isoline map can be transformed into a 3-D image (Kavouras 1995). Now many GIS programs allow the generation of 3-D views by draping cultural information over terrain models (Visvalingam 1994). Animation techniques in GIS are useful to depict the sequence of events corresponding to temporal processes such as growth and expansion (Hearnshaw 1994). Examples of animation techniques include simulations of landslides and glacial events (GeoSolutions 2004), fire incidents (Dodge 1996), and urban growth (Hasen 2001). In addition, animation techniques can allow viewers to virtually experience environments, real or imaginary, by using 3-D visualization techniques. For example, we can "fly" through an inaccessible study area and look at different GIS layers draped over a digital elevation model (DEM). In contrast to these many promising advantages of animation techniques, some researchers suggest that animations are limited in their ability to communicate, especially because animations are often too complex and/or too fast to be accurately perceived and may lead readers to perceive continuous events as sequences of discrete steps (Tversky and Morrison 2002).

Spatial Ability

This section reviews spatial ability in the context of GIS. First, this section defines spatial abilities and discusses limitations of traditional assessments of the individuals' spatial ability (e.g., psychometric tests). An overview of individual differences in spatial ability follows. Finally, this review discusses how GIS learning relates to spatial ability. This review provides a contextual background for the research questions such as how completion of a GIS course will affect the spatial ability of college students, and how these effects of GIS learning on spatial ability will be different for males and for females.

Definition of Spatial Ability

Cognitive psychologists, such as McGee (1979b), generally agree that spatial ability comprises several distinct but interrelated factors. Nevertheless, some disagreement still exists about whether there are two dominant dimensions–spatial visualization and spatial orientation–or whether a third–spatial relations–is also a fundamental dimension of spatial ability (Gilmartin and Patton 1984; Golledge and Stimson 1997; Linn and Petersen 1985; Lohman 1979; Montello et al. 1999; Vernon 1961).

Spatial visualization refers to the ability "to mentally rotate, manipulate, and twist two- and three-dimensional stimulus objects" (McGee 1979b, 896), or "to transform or to recognize a transformation of one element into another; to conjure up mental imagery and then to transform that imagery" (Gardner 1983, 176). Mentally creating a 3-D surface from a 2-D representation is also considered spatial visualization (Gilmartin and Patton 1984).

Spatial orientation involves "the comprehension of the arrangement of elements within a visual stimulus pattern, the aptitude to remain unconfused by the changing orientations in which a spatial configuration may be presented, and the ability to determine spatial orientation with respect to one's body" (McGee 1979b, 897). This refers to the ability to keep a clear idea of where the individual is situated in relation to the wider space in which he or she happens to be. Among the questions people often ask when trying to find some orientation in space is "If the environment looks like this, what is my position?" (Common Health of Massachusetts 2003). In geography, spatial orientation has been used to read and analyze maps, air photographs, and digital images (Gilmartin and Patton 1984).

Spatial relations has been suggested as a third component of spatial ability especially by geographers (Golledge 1993). Geographers have argued that psychologists have neglected some aspects of spatial phenomena such as distribution, process, association, and structure which are important elements used in spatial activities (Golledge 1993; Self and Gollege 1994). More specifically spatial relations refer to the

> … ability to recognize spatial distributions and spatial patterns, to connect locations, to associate and correlate spatially distributed phenomena, to comprehend and use spatial hierarchies, to regionalize, to orientate to real-world frames of reference, to imagine maps from verbal descriptions, to sketch map, to compare maps, and to overlay and dissolve maps (Golledge and Stimson 1997, 158).

Few, if any, of these abilities have been tested by psychometric tests developed by psychologists (Golledge and Stimson 1997).

Measurement of Spatial Ability

Another objection raised by geographers to psychometric tests is that the term “spatial” in these tests refers only to small-scale (table-top) spaces (Liben 1981). Space can be classified into two or more categories based on scale (e.g., Downs and Stea’s small- and large-scale spaces; Ittelson’s object and large-scale spaces; Mandler’s small-, medium-, and large-scale spaces; Montello’s figural, vista, environmental, and geographical spaces). The most common differentiation used in published research has been between small-scale and large-scale spaces.

Typically small-scale spaces can be apprehended from one single perspective, from outside of the space itself (Ittleson 1973; Mandler 1983). This is the space of pictures and small objects (Mondello 1993). The term “manipulable space” has been used to describe this type of space, although other terms have also been suggested, such as “table-top” space, “haptic” space, “sensormotor” space (Mandler 1983; Montello 1993).

Large-scale spaces, often referred to as environmental or geographic spaces, are larger than the human body and surround it (Mandler 1983; Mark and Freundschuh 1995). The spatial relationships between elements of large-scale spaces cannot be directly observed and must be reconstructed over time from experiences within the space (Downs and Stea 1973; Montello 1993). Whereas small-scale space has been explored primarily by psychologists concerned with the processes underlying environmental cognition, large-scale space has been studied by geographers interested in answering “what”, “where” and “why” questions in real-world situations (Spencer and Blades 1986).

Psychometric tests require individuals to find hidden shapes, match 2-D or 3-D figures, balance figures with respect to horizontal or vertical axes, solve mazes, and imagine the result of rotations or spatial manipulations of figures (e.g., Connor et al. 1978; Gilmartin and Patton 1984; Goldstein et al. 1990; Kail et al. 1979; McGlone 1981; Miller and Santoni 1986; Newcombe and Dubas 1992; Tapley and Bryden 1977). Psychometric tests, however, assess hardly any of the spatial abilities needed in real-world problem-solving situations (Allen 1999; Freundschuh 1992; Golledge 1993; Montello et al. 1999; Self et al. 1992). In addition, spatial relations–including spatial correlation, association, pattern, and structure–go beyond the abilities usually evaluated in psychometric tests (Self et al. 1992). Montello et al. (1999) and Golledge (1993) argued that:

> … the restricted definition of spatial ability, as incorporated into many psychometric tests, contrasts with the richness of the general literature on spatial activities and spatial behavior, much of it from disciplines other than psychology (Montello et al. 1999, 517).
>
> [Spatial knowledge] includes higher level concepts such as hierarchy, surface, association, connectivity, pattern, and so on. … Psychologists have neglected height or relief in their examination of spatial phenomena. In contrast, the geographer commonly represents spatial interactions, movements, or even the basic distribution or pattern of phenomena as surfaces. They are sometimes represented in two dimensional form and sometimes represented as three dimensional surfaces (Golledge 1993, 28).

Considering that GIS has been developed to deal with spatial information at the large/geographic scale (Golledge 1993; Mark and Freundschuh 1995), psychometric tests suffer obvious limitations for measuring the effects of GIS learning on spatial ability (Golledge 1993). The spatial features that psychometric tests are designed to measure are more related to jobs such as drafting, carpentry, art and design, architecture, and sewing/clothing design than geographic problem solving (Psychological Corporation 1972).

Even though it is still a relatively unexplained field, it is important to develop new types of assessment tools that can measure what psychometric tests cannot (Kali et al. 1997). For example, when measuring students' spatial visualization skills acquired from a geoscience class, Libarkin and Brick (2002, 453) noted that:

> Visualization in a specific topic requires a unique set of skills; visualization of earth processes requires spatial and temporal projections not encountered in available assessment tools. Certainly, the field would benefit from instruments specifically designed for studying learning in the earth system.

Kali et al. (1997) developed a new type of test for dealing with geologic spatial ability of college students. The test asked respondents to draw cross sections of structures presented as block diagrams and to imagine block diagrams that revealed only a single face. According to Bezzi (1991, 284):

> Drawing geological maps and cross sections requires one to visualize structural shapes in the mind's eye and to rotate, translate, and shear them. … This mental visualization … extends beyond the field of the earth sciences alone.

More recently, so-called "spatial analysis tests" were developed and applied in geographic education by researchers such as Audet and Abegg (1996), Kerski (2000), Meyer et al. (1999) and Olsen (2000). The spatial analysis test created by Kerski (2000) for example, asked students to choose the best site for a fast food restaurant in a hypothetical community based on given set of geographic (mapped) data such as traffic volume, existing fast food locations, locations of high schools, annual median income and zoning; students also ranked the same data according to its relative contribution to the final selection and provided explanations to support their decisions. However, few studies have examined the validity and reliability of this type of spatial analysis test.

Individual Differences in Spatial Ability

This section discusses whether spatial ability improves with training, and whether training affects individuals differently depending on their gender or major. Research concerning the impact of training on spatial ability has been inconsistent. For example, Baenninger and Newcombe (1989), Ben-Chaim et al. (1988), Bezzi (1991), Chadwick (1978), Kali and Orion (1996), Kali et al. (1997), Kiser (1990), Lord (1985; 1987), Saccuzzo et al. (1996), and Smith and Schroeder (1981) reported improvement in students' spatial ability with training. However, studies by Mendicino (1958) and Mundy

(1987) found no such improvements. This inconsistency may result from the variety of training programs and differences in spatial ability tests.

Researchers have also debated the existence and magnitude of gender differences in the acquisition of spatial ability. While some research suggested that there is no significant difference between men and women in spatial aptitude (Caplan et al. 1985), a number of other studies have argued for male superiority based on various spatial ability tests (Fennema 1975; Harris 1978; Hyde et al. 1975; Linn and Petersen 1985; Smith 1964). Better performances by men have been identified only in specific parts of spatial skills tests, and especially in visual-spatial tasks (Chadwick 1978; Harris 1978; Kali and Orion 1996; Liben 1981; Maccoby and Jacklin 1974; McGee 1979a; Sherman 1980).

Saccuzzo et al. (1996) also reported that men initially performed better than women in spatial ability tests. However, after training women showed significantly higher rates of improvement. But since men scored much closer to the maximum value in the initial spatial ability test, women could potentially improve more after training because their initial scores were lower (Connor et al. 1977; Goldstein and Chance 1965). Conversely, Baenninger and Newcombe (1989) and Sorby (1998 cited in Turos and Ervin 2000) suggested that both males and females have substantial room for improvement in spatial ability. Research about gender differences in GIS learning still remains insufficient and inconclusive (Baker and White 2003; Self et al. 1992).

Individual academic mastery in areas of knowledge like science has been considered as one of the main factors that can cause differences in performance of spatial aptitude tasks (Orin et al. 1997; Pallrand and Seeber 1984; Smith and Schroeder

1981). However, there has been little research on the relationship between individuals' academic major and GIS learning. One exception is Vincent (2004), who correlated students' demographic information such as learning styles, spatial ability, gender, and major to their achievement in a GIS course. His research did not find any significant correlation between students' academic major and performance in a GIS course.

GIS Learning and Spatial Ability

A positive relationship between GIS learning and spatial ability has been proposed by many researchers (Albert and Golledge 1999; Self et al. 1992). Identification of spatial activities employed by GIS users is a starting point to investigate the relationships between GIS learning and spatial ability (Bednarz 1995; Self et al. 1992). Self et al. (1992, 335-336), for example, suggested that:

> … both remote sensing and cartography requires spatial-visual skills and an understanding of spatial relations. Aerial photographic interpretation involves specific abilities, including feature identification, clustering and/or grouping, and recognition of spatial association. … Users of GIS techniques have to understand concepts that are uniquely spatial, such as scale, projection, geometry and topology. Geometric understanding, as evidenced by visualization tasks such as rotation, do appear to show gender differences.

Albert and Golledge (1999, 10-11) were the first researchers to connect GIS activities to the three components of spatial ability:

> … it [spatial visualization] may be very important in the use of GIS. In particular, spatial visualization ability may be extremely useful in tasks such as map overlay, since map overlay involves the comparison of individual spatial elements and the performance of a logical operation on those elements, hence manipulation. Spatial visualization may also be used in the rotation and geometric transformations of 2-D and 3-D graphic representation such as map layers and DEMs…

> … Spatial orientation may also play an important role in the use of GIS since GIS-users are often required to adopt new perspectives on 2-D and 3-D graphic representations such as a digital elevation model (DEM). In order for the GIS user to make any spatial inferences regarding shape, pattern, or layout, where the orientation of the subject is a factor, the user must adopt a new perspective, and therefore use aspects of spatial orientation….
>
> … This ability [spatial relations] may be important in specific GIS tasks in which mental rotation is not involved, such as the identification of features, as well as the clusters to which features belong, and the recognition of spatial association...

In related research, Lee and Bednarz (2004) also argued that the spatial relations dimension has a more direct correlation with GIS activities than spatial visualization and spatial orientation.

Cognitive Mapping and Problem Solving

This section reviews spatial problem solving in a context of GIS. Since students' spatial problem-solving strategies are measured by analysis of their map-drawing processes in a cognitive mapping task, this section focuses on methods to evaluate cognitive maps and cognitive mapping. This section provides the background context for the research question that investigates how completion of a GIS course will affect the map-drawing strategy of college students.

Researchers of environmental perception and cognition have used cognitive maps and cognitive mapping to study individual differences in spatial abilities (e.g., Appleyard 1970; Golledge and Stimson 1997; Hart and Moore 1973; Liben 1981; Lynch 1960; Moore 1973). Cognitive mapping may be defined as “the mental process through which people come to grip with and comprehend the world around them” (Downs and Stea

1977, 61). The product of this process can be considered as a cognitive map (Downs and Stea 1973).

Different methodologies have been used to study various aspects of cognitive maps and cognitive mapping (Anooshian and Siegel 1985). These methodologies include (1) mechanical approaches (e.g., counting items and evaluating the accuracy of distance estimation), (2) structural approaches (e.g., classifying maps based on the level of cognitive development), and (3) process-oriented approaches (e.g., looking at cognitive mapping as spatial problem solving).

Mechanical Approach

The simplest approach has been to count items in subjects' maps. According to Lynch (1960), cognitive maps contain five basic elements: paths, edges, nodes, districts and landmarks. Devlin (1976), Evans et al. (1981), and McNamara et al. (1989) tabulated the amount of spatial information, such as paths, nodes (path interactions), labels, and landmarks, that subjects put on their maps. However, people do not always map everything they see and remember (Foley and Cohen 1984). For example, the importance of roads is over-estimated if one uses sketch maps to evaluate spatial cognition as opposed to memory reports of subjects (Carr and Schissler 1969). Although individuals cannot map features they are not aware of, they might also choose to reduce the amount of information they map to prevent the maps from becoming cluttered or exceedingly detailed. Other researchers have assessed maps by measuring relative distance and the absolute coordinate errors (Antes et al. 1988; Briggs 1981; Brown and Broadway 1981; Cadwallader 1979; McGuinness and Sparks 1983).

These mechanical approaches have the common assumption that the quality of people's cognitive maps can be measured by comparing them to accurate Euclidean maps. Some researchers have found high correlations between perceived and actual distances (Baird 1979; Golledge and Zannaras 1973), but others point out that cognitive maps are always distorted with respect to Euclidean geometry, and thus the level of distortion will likely depend on individual differences such as their age, environmental experience, graphic skills, style of training, and patterns of thinking (Downs 1981; Downs and Stea 1973; Golledge and Stimson 1997). Non-Euclidean information also influences people's selection of landmarks (Hirtle and Jonides 1985), and several studies have shown that subjects' familiarity with, preference for, and the function of, routes and landmarks affect their ability to estimate distance accuracy (Antes et al. 1988; Canter and Tagg 1975; Lee 1970). Other researchers have identified additional distance estimation effects. For instance, Sadalla and Magel (1980) found that people consistently judged a route containing more turns as longer than one of the same length containing fewer turns. Sadalla and Staplin (1980) found that routes with fewer interactions were estimated to be shorter than those with more interactions. Kosslyn et al. (1974) reported that both preschoolers and adults overestimated the distance of a route containing a large opaque barrier, compared to a route with no barrier. This study suggests that an adequate model of mental mapping cannot be built around a strictly Euclidean conception.

Structural Approach

In contrast to mechanically analyzing the accuracy and amount of information included in cognitive maps, the structural approach classifies cognitive maps based on the developmental level of the spatial abilities required to draw the maps. This approach implies that cognitive maps possess kinds of structural properties that we are familiar with in "real" cartographic maps (Boyle and Robinson 1979). Most of this work is based on Piaget's extensive theorizing about spatial ontogeny, including his idea that people progress from topological to projective and metric knowledge (Piaget and Inhelder 1967). For example, Hart and Moore (1973) discussed three categories of reference systems–egocentric, fixed, and coordinated–observed in cognitive maps. A few findings in the environmental cognition literature supported the Piagetian hypothesis. For instance, Moore (1973) had independent judges classify adults' sketch maps based on their developmental level. Maps judged as level I (egocentric) maps organized undifferentiated elements from a personal perspective. These maps typically included serpentine-like routes comprised of personally significant street segments bearing little resemblance to the actual geographical relations between these streets. Level II (linear-route) maps were partially coordinated and organized around one or two different referent points. Level III (abstract coordinated) maps were characterized by features of interest embedded in an overall geometric organization.

In related research, Appleyard (1970) found that sketch maps drawn of Cuidad Guayana by 320 inhabitants were structured either sequentially, using roads and rivers as organizing features, or spatially, using buildings and districts (Fig. 2). The better educated residents produced spatially structured maps rather than sequential maps. Appleyard's conclusion that sequential maps were of a lower developmental order than spatial maps supported the findings of Shemyakin (1962), who used the terms "route map" and "survey map" to classify the developmental stage of representation in cognitive maps. According to Shemyakin (1962), a route map consists of a sequence of landmarks identifying a particular location. With more experience, information about different routes is integrated into a network-like structure, producing a survey map.

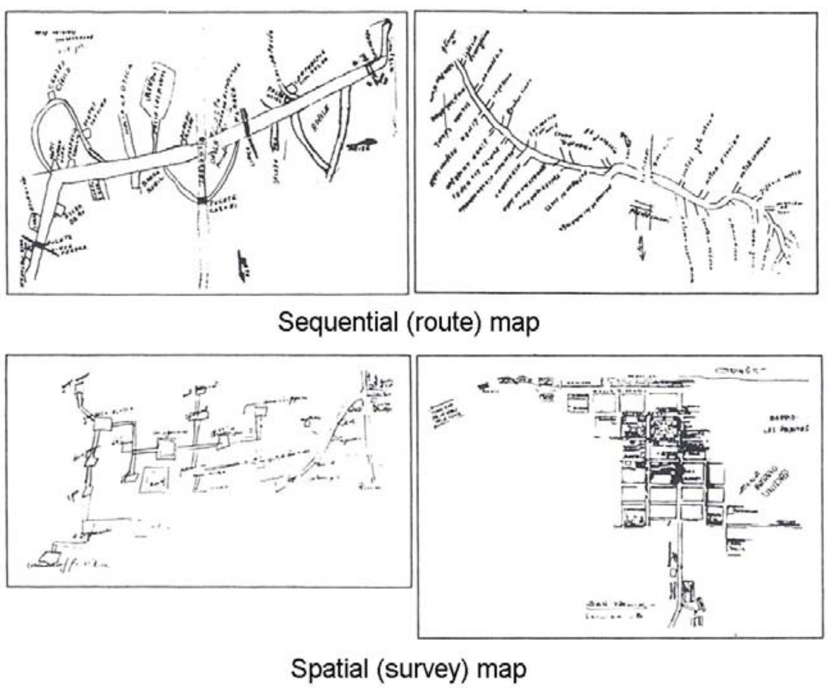


Fig. 2. The sequential and spatial map from Applyard (1970).

Appleyard (1970) reported that differences in structuring cognitive maps were caused more by cognitive differences, travel mode, and familiarity than by other personal variables such as age, sex, and occupation. Miller and Santoni (1986) found significant correlations between accuracy in map use and the completion of specific courses such as math. Moore (1979) went on to argue that the overall education level was not important in the construction of cognitive maps, but what was more important was the development of specific cognitive abilities needed for processing spatial information. Moore (1975a; 1975b) compared the scores in spatial skills from the Differential Aptitude Test (DAT) with the level of cognitive mapping performance of high school students. The results indicated that none of the verbal reasoning or numerical ability scores was significantly correlated to the level of cognitive mapping performance. There was, however, a highly significant and strong correlation between spatial ability and the developmental level of students' cognitive maps. This finding was supported by O'Laughlin and Brubaker (1988) who reported a positive relationship between participants' performance on the Mental Rotation Test (MRT) and a cognitive map task.

Process-Oriented Approach

The process-oriented approach helps us to get away from focusing on the finished map (product), and to refocus on spatial problem solving as an intrinsic characteristic of cognitive mapping (Downs 1981). When drawing cognitive maps, people have to deal with spatial problems such as selecting information from their spatial environment and converting it into organized representations, thus translating information from the large-scale space of the real world into the small-scale space of a piece of paper (Beck and

Wood 1976; Downs and Stea 1977; Kuipers 1978; Siegel 1981). The following quotations provide additional examples of problems people confront during cognitive mapping.

> In producing the street map, we have to decide upon its purpose. Who is it for: Will it be for pedestrians or drivers, for strangers to the city or current residents, for sightseeing or everyday living? The answer to this question is crucial since it determines both who the representation is useful to, and what types of spatial problem it can assist in solving (Downs and Stea 1977; 64).

> [The cognitive mapping] process generates plans for solving specific spatial problems (Downs and Stea 1977, 68).

> This mapmaking requirement involves decisions about what types of information we store, how we symbolize it, how we arrange and order it, and how we attach relative value or importance to it (Downs and Stea 1977, 77).

> The visual scene presents one view of the space, while the map presents an alternative representation. In order to accurately decide which way to go, it is necessary to bring these two views of the space into correspondence. … Mental transformations may need to be done in order to coordinate these views to make accurate decision (Gunzelmann and Anderson 2002, 387).

> The representation and operations upon it [cognitive map] tell us how the person solves a problem, remembers a sentence, answers a question or makes a decision (Trabasso and Riley 1975, 381).

Since cognitive mapping and GIS use require people to rely on common mental processes, GIS learning should affect people's spatial ability and spatial problem solving. Actually, Golledge (1993) suggested that cognitive mapping is like an internalized GIS in order to emphasize the common processes employed by GIS users and cognitive mappers.

> The rapid development of GIS as a means for coding, storing, accessing, analyzing, representing and using spatial data creates an obvious parallel with the cognitive mapping process – which also encodes, stores, internally manipulates, decodes and represents spatial information. We offer a metaphor that may be useful when dealing with both concepts –i.e., that the cognitive map is an

internalized GIS (Golledge and Bell 1995, 1).

Another reason why cognitive mapping is a good measure of spatial ability is that cognitive mapping requires mappers to use most of the skills in the proposed definition of spatial relations such as recognizing spatial distributions and patterns, connecting locations, associating spatial phenomena, comprehending spatial hierarchies, and regionalizing. However, little is known about the relationship between specific spatial abilities and cognitive map formation, or which abilities make the most important contribution to cognitive map learning (Allen 1999; Kitchin and Blades 2002).

How People Draw a Map: Map-drawing Strategy

Kitchin (1997) argues that commonly used strategies employed in a cognitive-mapping task can be identified objectively. However, there have been few attempts to reveal which strategies are used in constructing cognitive maps (Foley and Cohen 1984). Some possible research questions might include: "What strategies are used to construct cognitive maps?" "How many strategies are used to construct cognitive maps?" "Do different strategies (cognitive mapping) lead to different results (cognitive maps)?"

Although not much has been written about the process of creating cognitive maps (Kitchin 1997), research concerning the "anchor hypothesis" (Couclelis et al. 1987; Golledge 1978; Golledge and Zannaras 1973)" and the "rational analysis framework" (Anderson 1990; 1991) offers a starting point.

An "anchor" is a personal, familiar landmark that serves as a reference point for a region of space. Cognitive maps are organized according to reference points known as anchors. Anchors (or reference points) are closely related to Lynch's (1960) landmarks. The concept of landmark has multiple referents. The term has been used to denote (a) discriminable features along a route, that signals navigational decisions; (b) discriminable features of a region, that allow a subject to maintain a general geographical orientation; and (c) salient information in a memory task (Sadalla et al. 1980). Anchors tend to be large, have important functions in the environment, and be perceived as a point feature such as a building. Nevertheless rivers and roads, classified as paths by Lynch (1960), are able to function as anchors too. According to Ferguson and Hegarty (1994), linear landmarks are remembered better than point landmarks because they occupy a larger amount of space.

These anchors and the linkages between them provide a skeletal hierarchical structure for representing and organizing cognitive information about space (Couclelis et al. 1987). Because a reference point is regarded as a place that defines the position of other adjacent places, it follows that other places are seen "in spatial relation to" a reference point rather than vice versa (Rosch 1975). Researchers hypothesized that a system having a number of reference locations from which the location of other places could be computed would make fewer demands on an individual's storage capacity than would a system that tried to represent the spatial relationships between all known locations (Sadalla et al. 1980). The relation between "anchors" and details has been understood as function of hierarchy. A large-scale external environment such as urban area can be conceptualized as a collection of parts. These parts consist of a set of hierarchical nodes, hierarchical paths connecting the nodes, and areas of various scales and with various degrees of generalization (Golledge 1978). The location of different places is known with different degrees of certainty (Sadalla et al. 1980). The locations of anchors are represented at a higher level of the hierarchical scheme whereas other landmarks are represented at a lower level, inferred from the locations of their anchors (Stevens and Coupe 1978).

One method for discovering the hierarchy implicit in a cognitive representation is to examine the order in which people include landmarks when drawing their maps. If anchors are functioning as reference points, they should be drawn before other landmarks so that landmarks can be located with respect to anchors. By videotaping the order in which people create a map, this assumption can be verified. In order to deduce mappers' spatial skills and knowledge used for their cognitive maps, one must be able to identify the mappers' strategy accurately. Although individuals often record the same things on their cognitive maps, there is no evidence that they record them in the same way (Billinghurst and Weghorst 1995; Lohman and Kyllonen 1983). As the present study will show, it is frequently difficult to determine a mapper's strategy solely by examining a finished map.

While the anchor analysis theory deals with the structural process of map-drawing, the rational analysis framework focuses on the decision-making aspects of cognitive mapping. To solve a problem requires the determination of a sequence of decisions (Anderson 1991). Problem solving research shows that people seldom plan complete sequences of actions before acting (Anderson 1990; Gunzelmann and Anderson 2003). As several authors (e.g., Anderson 1990; O'Hara and Payne 1998) have pointed out, problem solvers construct partial plans, execute the action based on the partial plans, and keep planning as they act. Therefore, every problem-solving behavior lies somewhere along the continuum between the following two extremes:

> At one extreme, a single action is decided and executed based purely on the current state of the problem. … However, this usually leads to inefficient solutions to the problem. At the other extreme of the planning continuum, a complete sequence of action is planned out before any action is executed. This results in highly efficient performance, as the best sequence of actions can be chosen and executed. However, the costs associated with planning often nullify any benefit that the planning can bring (Fu 2003, 99).

One explanation for this kind of trade-off was given by Anderson (1990) who perceived the operation of human memory as an optimization process. In his rational analysis, human memory maximizes the expected utility of the memory system by balancing each cost against an expected gain.

> With respect to problem solving it was assumed that the goal of the system was to achieve certain states of affairs (e.g., getting from one location to another). Achieving a state of affairs has some value, G. The problem solver is characterized as searching for some plan which will achieve this state of affairs. Any plan is characterized as having a certain cost, C, and probability of success, P. The rational behavior is one of choosing among plans to find one that maximizes PG – C and executing it, provided its expected value is positive (Anderson 1991, 481).

Thus, under the rational framework, the planning process should stop as soon as the cost of further planning exceeds the benefit that further planning could bring (Christensen-Szalanski 1980). The idea is that continued search for answers to the problem takes place at increasing costs. That is, a problem solver reaches temporary satisfaction by selecting the best plan at the time, without any guarantee that it will be the best overall option.

In order to understand the problem-solving process in cognitive mapping, it is not sufficient to consider just the internal representation of the task and how this task is processed. For example, the interleaving of planning (internal representation) and action (drawing) allows for additional reactive and opportunistic planning actions (O'Hara and Payne 1998). Additionally, implementing representation tools in the planning process reduces both uncertainty in the problem-solving process and the load on working memory (Anderson 1991; Kirsh and Maglio 1994).

In summary, some people solve spatial problems based on more developed long-range plans, while others solve spatial problems based on short-range plans. For example, when people attempt to find the shortest route from location A to location B, they have to consider several spatial variables such as traveling time, distance, road conditions, traffic signs, speed limits, construction sites, etc. People who consider several variables simultaneously and plan further will likely produce more efficient solutions to their problems when compared to people who consider fewer variables. However, individuals cannot hold a long sequence of actions in their minds due to the limits of their memory (Anderson 1991). Thus, more plan-based strategies require greater cognitive efforts that often result in additional time costs.

Since strategies that are based on short-range plans require less cognitive effort, these strategies allow for quicker responses to changing external conditions. However, strategies using short-range plans often lead to limited solutions that require more trial and error sequences in order to reach the same goal, often resulting in less efficient solutions to the problem (Fu 2003; O'Hara and Payne 1998).

Relationship between Aptitude and Strategy Choice

This review provides a framework and rationale to understand the research questions such as whether there is a relationship between students' map-drawing strategies and spatial ability. This section reviews relationships between spatial ability and (spatial problem-solving) strategy choice. An overview of the major research findings concerning the effects of spatial aptitude on spatial task performance follows.

Researchers agree that different people do employ different strategies when solving the same spatial tasks (Anzai and Simon 1979; Kyllonen et al. 1984a, 1984b; Lohman and Kyllonen 1983). It is quite unclear, however, how these different spatial strategies come about. They may be caused by variations in cognitive styles, or they may be due to individual differences in spatial ability. Therefore, it is fundamental to study the relationship between individual aptitude and strategy choice.

Is there a relationship between aptitude and strategy? Kyllonen et al. (1984a) and Lohman and Kyllonen (1983) identified three possible types of aptitude-strategy relations. In the first case strategy selection is limited by aptitude, because the use of a strategy requires particular skills. Differences in how subjects solve problems are entirely a function of differences in aptitude. Consequently, the strategy is the aptitude (Lohman and Kyllonen 1983). In the second case strategy choice is not related to aptitude; the effectiveness in solving tasks depends on the aptitudes required by each strategy. In this case, strategy is important for understanding task performance, but irrelevant for understanding aptitude (Lohman and Kyllonen 1983). In the third case the relationship between aptitude and strategy combines the first two types of aptitude-strategy relations: Aptitude limits both strategic choices and effectiveness in the use of the selected strategy.

There is evidence that subjects' ability plays a role in their strategy choices and efficiency (Freedman and Rovegno 1981; Lohman and Kyllonen 1983; Kyllonen et al 1984a; 1984b; Schultz 1991; Snow 1980). For example, Freedman and Rovegno (1981) investigated strategies for a mental rotation test using a retrospective questionnaire. They reported that high-ability individuals, males, and right-handed individuals tend to use more nonverbal, holistic strategies than their counterparts. In related research, Kali et al. (1979) examined gender differences on a mental rotation task and concluded that some subjects rotated an image holistically, while others compared selected features sequentially and analytically; female participants used the latter strategy more often.

In theory, subjects who use holistic strategies take longer to solve problems, since they must perform mental manipulations of the figures. In contrast, subjects using analytic strategy select a feature on the target figures and check it against the response figure, alternating looks at the target and response figures (Bruin et al. 2000). Snow (1978; 1980) found that high-ability subjects tend to choose more constructive matching strategies, whereas low-ability subjects choose more response-elimination strategies.

Other studies did not find these types of relationships between aptitude, strategy choice, and performance (e.g., Bruin et al. 2000; Latwon 1994; O'Laughlin and Brubaker 1988). For instance, Latwon (1994) found no relationship between mental rotation ability and way-finding strategy, which is a behavior dependent upon the process of cognitive mapping (O'Laughlin and Brubaker 1998). In examining strategic and gender differences in solving a spatial visualization task, Bruin et al. (2000) reported that strategy choice was not related to aptitude level or gender. Tapley and Bryden (1977) concluded that strategy was not related to performance accuracy either for real object or mental rotation tasks.

In summary, existing research on this topic is still insufficient and inconclusive to determine the relationship between aptitude and strategy choice (Bruin et al. 2000). Furthermore, there is little research concerning different map-drawing strategies in a context of spatial aptitude. However, it is clear that individual differences in spatial strategy are relevant to spatial performance. A better understanding of strategy choice and its relationship to spatial performances will be an important further for the understanding of variations in spatial ability (Schultz 1991).

Summary

The purpose of this literature review was to provide background and context for research questions concerning the effect of GIS learning on spatial ability and spatial problem solving. The most relevant research performed in this field is summarized as follows.

GIS is different from other information processing systems due to its emphasis on spatial analysis and spatial visualization functions (Anseline and Getis 1992; Cowen 1988; Goodchild 1987; Maguire 1991). GIS analytical methods including spatial measurements, calculations, spatial queries, and spatial statistics can improve students' analytical skills and spatial reasoning (Hall- Barstow 1994; Thompson et al. 1997;

Wallace and McAuliffe 2002). GIS visualization serves as a tool for visual thinking and scientific inquiry by offering dramatically different ways of looking at problems (Gordin and Pea 1995; MacEachren et al. 1992; Medyckyj-Scott 1994).

Definitions of spatial abilities are tied to performance on spatial aptitude tests and to the dimensions of visualization and orientation contained within those tests (Golledge and Stimson 1997). Golledeg (1993) also suggested that spatial relations is the third dimension of spatial ability, and it includes characteristics such as spatial correlation, association, pattern, and structure. Although psychometric tests have been widely used to measure spatial ability, they have limitations to assess spatial relations, which is the element most closely related to GIS activities. More recently so-called "spatial analysis tests" were developed to measure participants' spatial problem solving in geographic educational research (e.g., Audet and Abegg 1996; Kerski 2000; Meyer et al. 1999; Olsen 2000). However, few studies have examined the validity and reliability of this type of spatial analysis test.

Since cognitive mapping and GIS use make people rely on common mental processes, GIS learning should affect people's spatial problem solving. For example, when drawing cognitive maps, people have to deal with spatial problems such as selecting information from their spatial environment and converting it into organized representations, thus translating information from the large-scale space of the real world into the small-scale space of a piece of paper (Beck and Wood 1976; Downs and Stea 1977; Kuipers 1978; Siegel 1981). Analyzing videotaped map-drawing processes can provide more information than the analysis of finished paper maps. Although not much has been written about the process of creating cognitive maps (Kitchin 1997), research concerning the "anchor hypothesis" (Couclelis et al. 1987; Golledge 1978; Golledge and Zannaras 1973)" and the "rational analysis framework" (Anderson 1990; 1991) offers a starting point.

Researchers agree that different people employ different strategies when solving the same spatial tasks (Anzai and Simon 1979; Kyllonen et al. 1984a, 1984b; Lohman and Kyllonen 1983). It is quite unclear, however, how these different spatial strategies come about. It has been suggested that the subjects' abilities play a role in their strategy choices and efficiency (Freedman and Rovegno 1981; Lohman and Kyllonen 1983; Kyllonen et al. 1984a, 1984b; Schultz 1991; Snow 1980). The same principle can be applied to understand the relationships between spatial ability and a choice of cognitive-mapping strategy.

CHAPTER III

RESEARCH METHODOLOGY

Two research assessments were conducted to measure changes in spatial ability and spatial problem solving of students, before and after they completed a GIS course. This chapter describes the research design and methods involved in these two assessments: a spatial skills test and a cognitive-mapping test.

Experiment 1: Spatial Skills Test

Experiment #1 was devised to determine whether the completion of a GIS course changed the spatial ability of college students. In order to address this issue comprehensively, the experiment considered a series of related factors such as whether students with different gender or academic major perform in a comparable way after completion of a GIS course, whether the completion of a computer cartography course was equally effective as the completion of a GIS course for the improvement of spatial ability, and whether there was a relationship between students' scores on the spatial skills test and their performance in a GIS course.

Test Descriptions

Spatial relations is the dimension of spatial ability that has the closest correlation with GIS activities. It has a stronger correlation with GIS than either spatial visualization or spatial orientation, two other spatial dimensions that have been frequently used in psychological research (Lee and Bednarz, 2004). However, because there are no standardized tests dealing with the spatial relations dimension, a new test was developed for this study. The development of this spatial skills test followed these steps: (1) identification of the test purpose and specification of concepts measured, (2) construction of the initial pool of items, (3) pilot testing, (4) item analysis, and (5) field testing.

The initial step in the construction of a test is the delineation of the assessment objective. This process includes a description of the test content and constructs to be measured (Plake and Jones 2002). A careful specification of the test content also helps to improve its content validity. The spatial relations defined by Golledge and Stimson (1997) provided a guideline for developing test contents. Each test item was designed to measure a component or a trait of spatial relations as defined by Golledge and Stimson (1997). The spatial skills test consists of a set of multiple-choice questions and performance exercises (APPENDIX 1).

The final version of the spatial skills test includes seven types of question items: (1) overlaying and dissolving a map, (2) choosing the best location based on several spatial factors, (3) orienting to a real world frame of reference, (4) imagining maps from verbal descriptions, (5) correlating spatially distributed phenomena, (6) constructing contours based on point data, and (7) recognizing spatial data types (e.g., point, line, or polygon). The following is a description of the item types in the study, including how each one is related to GIS activities, and which traits each item aims to measure.

Item #1 required the participants to visually verify a map overlay process and then select the appropriate map layers involved in the overlay. The map overlay operation was selected because it is a fundamental GIS operation which requires spatial cognitive abilities to mentally visualize and manipulate spatial objects (Albert and Golledge 1999).

Item #2 required participants to select an ideal location for a store based on multiple pieces of spatial information such as population density and distance from already existing stores. The basic rationale behind items #1 and #2 is to assess Boolean logic, frequently used in GIS spatial analysis. In contrast to item #1, which involves abstract problem solving, item #2 emphasizes situational problem solving. Both items #1and #2 correspond to the trait "overlaying and dissolving maps" in the spatial relations discussed by Golledge and Stimson (1997).

In item #3, participants were asked to mentally visualize real-world topography based on the observation of a topographic map. Many modern GIS programs allow for the generation of 3-D views by draping corresponding cultural information over terrain models or surfaces (Visvalingam 1994). This item was necessary since participants, while generating 3-D images based on 2-D information, may perform several cognitive tasks including 2-D to 3-D conversion and spatial orientation in real-world situations. This item assesses the trait of "orienting to real-world frames of reference" referred to by Golledge and Stimson (1997).

In item #4, participants were required to locate specific places on a grid map based only on the analysis of verbal descriptions. In order to accurately complete this test item, the students had to critically interpret and synthesize two different types of visual information (a grid map and a selected topographic profile) and a verbal description.

This item measures the trait “imagining maps from verbal descriptions” mentioned by Golledge and Stimson (1997).

Item #5 asked participants to identify spatial correlations between sets of maps. GIS users are frequently required to compare several layers of spatial information pertaining to the same area in the screen. They may have to perform spatial cognitive processes, such as “comparing, associating and correlating spatially distributed phenomena,” and “recognizing spatial distributions and spatial patterns” (Golledge and Stimson 1997).

Item #6 required the participants to create a contour map by connecting points having the same elevation. In order to complete a contour map, students had to estimate the elevation of places having no labeled data points. Even though GIS can perform automated interpolations, students may be required to understand the process. This item evaluates the trait “associating and estimating spatially distributed phenomena” discussed by Golledge and Stimson (1997).

Finally item #7 asked participants to visually extract types of spatial data from visually or verbally expressed spatial information. The recognition of spatial data types (e.g., point, line, or polygon) is important for GIS users, especially for GIS data management or spatial analysis. In solving this problem, participants dealt with several cognitive traits including “imagining maps from verbal descriptions,” and “recognizing spatial patterns” also discussed by Golledge and Stimson (1997).

Administering a pilot test to a representative sample of the population is an important element in test preparation (Plake and Jones 2002). In this study, once a test with 25 test items was developed, a pilot test was administered at the end of the 2003 spring semester. A total of 86 subjects (49 males and 37 females) took part in the test. All subjects were classified as undergraduate or graduate students at Texas A&M University. They were recruited from several geography courses including Computer Cartography, Introduction to GIS, Advanced GIS, and Economic Geography. Each received $5 for his or her participation.

Performance on the pilot test was measured based on the total number of questions correctly answered. Item analyses were conducted for each question to evaluate clarity, reliability, content validity, discrimination ability, and difficulty level. Items that were too difficult, too easy, or unclear were eliminated or revised. By comparing the scores between a control group (non-GIS users) and experimental groups (GIS users) and by calculating the correlation between the number of GIS coursework hours finished by GIS users and their scores on the test, it was possible to determine the correlation between GIS learning experience and spatial abilities. The average scores of the control group, those with no GIS experience, were compared to three experimental groups who had completed (1) a cartography course only, (2) a GIS course only, or (3) more than two GIS courses (Table 2). Preliminary results suggested that the average scores of all three experimental groups were higher than the control group's ($p = 0.00$). A positive correlation existed between the number of GIS courses completed by the subjects and their scores on the spatial skills test (Pearson correlation coefficient = .578) (Fig. 3). Since a pretest was not administered, it was not possible to determine whether spatial abilities were improved by completing GIS courses. After the pilot test, 17 test items were selected for field testing.

Table 2. Average scores and standard deviations in the pilot test.

	No GIS experience	Cartography only	GIS only	More than 2 GIS courses	Average
Average	15.59	24.25	23.49	27.31	22.67
N	23	18	19	26	
S.D.	5.86	3.59	7.13	5.79	7.27

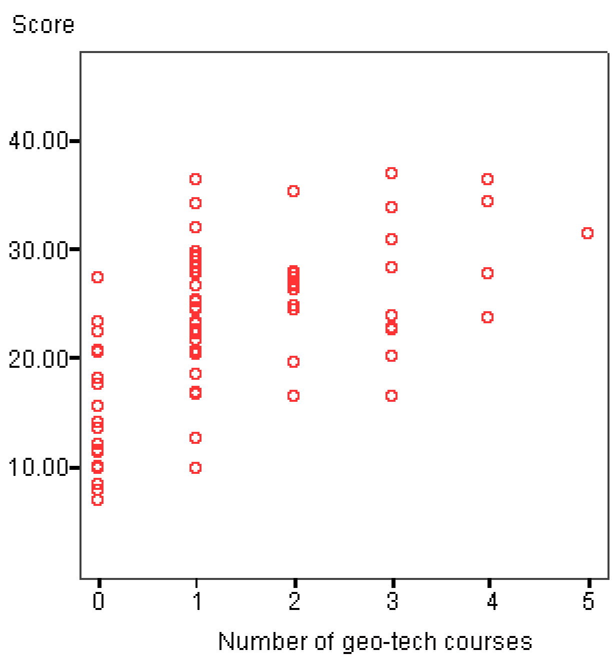


Fig. 3. Number of GIS courses completed by the subjects and their average scores in the spatial skills test.

Subjects and Test Setting

Participants for field tests were recruited from students enrolled in Computer

Cartography, Introduction to GIS, and Economic Geography in the Department of Geography at Texas A&M University during the 2003 fall semester. A total of 80 students completed both pre- and posttests at the beginning and end of the semester. During this semester, 17 and 18 students took Introduction to GIS and Computer Cartography respectively. Seven of the students enrolled in the Introduction to GIS course had already finished the Computer Cartography course before the pretest was administered. In addition, three students took both courses concurrently. Including Computer Cartography students in the experiment provided an opportunity to compare the effect on spatial ability of the completion of a GIS course with that of a cartography course (Table 3).

Table 3. Control group and three experimental groups.

Group		Group description
Control group (N=35)		Students who have not taken a GIS or cartography course.
Experimental group	Cartography (N=18)	Students who completed only a cartography course.
	GIS (N=17)	Students who completed only an introductory GIS course.
	GIS and Cartography (N=10)	Students who completed both a cartography and an introductory GIS course consecutively or concurrently.

Introduction to GIS consisted of two lectures and one lab per week. While lectures emphasized the underlying principles of GIS and its basic concepts of design, planning, and implementation, the laboratory component provided hands-on experience with GIS software frequently used in the real-world GIS community, namely ESRI ArcView, Arc/Info, and ArcGIS. Lab exercises included topics such as basic GIS data models; GIS data input, storage, and editing; elementary spatial measurement; analysis of spatial arrangements; overlay analysis; cartographic visualization; and GIS modeling. By the end of the semester, students were expected to complete either a GIS project or a paper as the final assignment. Final grades were assigned based on student performance on two exams, the lab exercises, and the final project or paper.

The Computer Cartography course was a combination of traditional cartography and GIS. This course also combined lectures with laboratory exercises. Lectures covered basic cartographic concepts and design principles, while laboratory exercises provided students with hands-on experiences of map design and production in ArcView and MS Office. Among the types of maps studied in the course were choropleth maps, dot maps, proportional circle maps, flow maps, and cartograms.

The purpose of the course on Economic Geography was to acquaint students with the basic principles of economics within a spatial context. The course explored topics such as the process of globalization, technological development, the dynamic relationship between the market and the state, and the role of transnational corporations. Economic Geography was primarily a lecture-based course.

Since random assignment of subjects to the control and experimental groups was not possible, a quasi-experimental method was used to measure the effect of the independent variable (completion of GIS course or cartography course) on the dependent variable (scores on the spatial skills test). This quasi-experimental method is the most appropriate method to attempt to show the "effectiveness" of a particular treatment–that is, it is a method that can claim to show both "cause" and "effect." A pre- and posttest control group design was used for this study (Table 4).

Table 4. The type of quasi-experimental design used in experiment 1.

	Pretest	Treatment	Posttest
Experimental	01	X	02
Control	01		02

Test Administration

Participants were given 30 minutes to complete the spatial skills test. They were also asked for background information regarding their gender and declared major, and whether they had previously taken any GIS courses. The pre- and posttests were composed of slightly different questions covering the same spatial abilities. After the pretest was conducted, no feedback was given to the students concerning their performance. Subjects received $3 for participating in the pre- and posttest of the spatial skills test.

Data Scoring and Analysis

Performance on the spatial skills test was measured based on the total number of questions answered correctly. According to the difficulty level and required time to solve each question, a weight was assigned to each item. The average score for each student group was analyzed using analysis of variance (ANOVA), analysis of covariance

(ANCOVA), and a paired sample *t-test*. An alpha level of .05 was used to determine whether there was significant difference between or among groups. If a significant difference among groups occurred, *post hoc* comparison (using Tukey and Bonferroni tests) was used to identify where differences had occurred.

In addition, personal interviews with the subjects who completed the GIS course were conducted to gather information about the learning process they perceived had occurred during the GIS course. Interview questions asked for a general evaluation of the teaching style (lecture vs. lab) and about the advantage of completing a final project in the course.

Experiment 2: Cognitive-Mapping Test

Research Questions

Experiment #2 was created to determine if GIS learning led to changes in the students' problem-solving strategies. These changes were measured by observing and analyzing the participants' map-drawing strategies. A previously administered pilot test revealed that hierarchical, regional, and mixed map-drawing strategies were the three types used by students. Comparisons of students' map-drawing strategies were made before and after they completed their GIS learning experience. In addition, the correlation between each map-drawing strategy and the corresponding average scores in the spatial skills test was also calculated.

Subjects

The participants were recruited from the students enrolled in the Introduction to GIS and Computer Cartography courses at Texas A&M University during the 2003 fall semester. A total of 64 students completed both pre- and posttests administered at the beginning and end of the semester. Of the 64 subjects, about half (36 of 64) were geography majors. Subjects received $3 for participating in both the pre- and posttest.

Test Descriptions and Procedure

The participants were asked to draw a sketch map of a familiar region based on the instructions that follow (Fig. 4). Map-drawing scenario was developed by the researcher (APPENDIX 2).

> Map-drawing scenario: A friend of yours is coming to visit you here. You are unable to show your friend around. Draw a map to help your friend find some useful places in town. This map should include the O&M building (location of the Dept. of Geography), Best Buy (a large electronics store), HEB (a grocery store), and Hollywood 16 (movie theater).

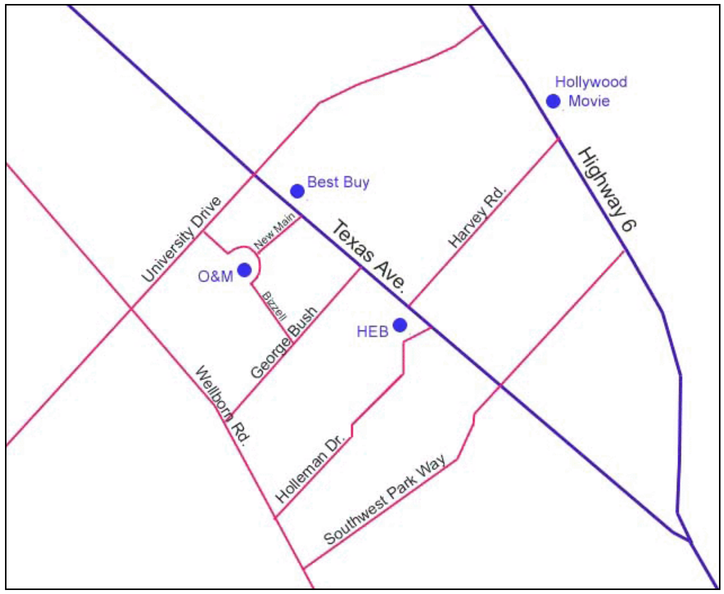


Fig. 4. Reference map.

For the posttest, the participants were asked to locate three different commercial locations (e.g., Barns & Noble, Target, and Sam's Club). By selecting three different places located near the three places used on the pretest, the pre- and posttest should be able to maintain consistency. The target area for the cognitive-mapping task is a part of College Station where the Texas A&M University campus is located. Two main roads, Texas Avenue and Highway 6, traverse the target area. All four of the locations subjects were asked to map are situated within 2 miles of the campus and are businesses frequented by almost all students.

Each student was given an 8.5 by 11 inch sheet of white paper. Subjects were given as long as necessary to complete their maps. Most of the subjects completed their maps within 10 minutes. The map-drawing process of each subject was videotaped in order to identify the subject's map organization method. The subjects were also asked how long they had lived in College Station; their usual mode of transportation; and their declared major, age, gender, and year in school (freshman, sophomore, etc.).

After the posttest of the cognitive-mapping task, interviews with 30 subjects were conducted in order to develop a richer understating of their map-drawing strategies. The students' videotapes were used to help the subjects recall their drawing experience. The interviewer asked subjects about their map-drawing strategies, the order in which they constructed the map, the location of their viewpoint (i.e., their orientation), and their familiarity with the area. The interview began by asking students to describe their mapping strategies as they watched the video tapes of themselves. After students described the mapping procedure in their own words, they were asked to answer specific questions such as "Why did you start with Highway 6 (a main road)?", "How did you orientate yourself?", "Where was your viewpoint?", "Why did you begin with upper-left (or upper right) corner of a paper?", "Why did you use a double line (or single line) for road construction?", and "Are you familiar with the mapping area?" Each interview was tape-recorded and transcribed.

Pilot Tests

Pre- and posttest versions of the cognitive-mapping test were administered as part of a pilot study in the 2003 spring semester. The participants (N=8) were undergraduate students registered in Computer Cartography at Texas A&M University. Through the analysis of the pilot test results, three map-drawing strategies were identified: hierarchical, regional, or mixed. Only minor changes in map-drawing strategies were found from pre- to posttest. The findings were, however, restricted due to the relatively small sample size.

Analysis

The respondents' map-drawing strategies were classified as hierarchical, regional, or mixed based on the recorded data. The average time used for each map-drawing strategy was calculated. By comparing the subjects' map-drawing strategies in the pre- and posttest, changes in map-drawing strategies after the completion of a GIS or cartography course were identified. The correlation between each map-drawing strategy and its corresponding average scores on the spatial skills test was determined. However, no attempt was made to measure the relationship between the complexity of maps and the average time used for drawing them.

CHAPTER IV

FINDINGS AND ANALYSIS

This chapter examines the statistical and qualitative outcome of the two research experiments described in Chapter III. The results are presented in the same order as the research experiments. Experiment #1 dealt with the spatial skills test. First, analyses of the participants' scores in the test were conducted to determine whether any differences existed between the control and experimental groups. Second, the effects of the variables related to the subjects' background, such as gender and major, were examined. Lastly, the correlation between the participants' average scores on the spatial skills test and performance in the GIS course were analyzed.

Experiment #2 involved the cognitive-mapping test. First, participants' map-drawing strategies were classified into three strategies (hierarchical, regional, and mixed) and any changes in their map-drawing strategies from pre- to posttest were determined. Qualitative data collected during interviews with subjects is reported in this section. Second, demographic information about the participants was correlated with the three map-drawing strategies. Lastly, participants' map-drawing strategies were correlated to their average scores in the spatial skills tests.

Experiment 1: Spatial Skills Test

Test Reliability

In the context of a performance assessment, issues of reliability are generally of great concern (Baker and White 2003). The reliability of the spatial skills test was analyzed according to the internal consistency reliability method. This method requires neither splitting of items into halves nor multiple administrations of instruments (Walsh and Betz 2001). As the spatial skills test was a mixture of dichotomous and multi-point scales, Cronbach's alpha, the most popular internal consistency reliability estimate, was used. Reliability analysis using SPSS was applied to the pretest (17 items). When three items that were causing substantial decrease in the value of alpha were eliminated, Cronbach's alpha increased to .7034 – a value considered acceptable (.70 is the cutoff value for acceptability). High values of alpha indicate that the items are measuring the same variable. Consequently the performance of each item is related to the performance of the test as a whole (Walsh and Betz 2001).

Score Comparison by Group

Participants' performances on the pre- and post- spatial skills test by group are shown in Table 5 and Fig. 5. Based on this data, two questions could be answered: (1) Are pretest scores different? And, (2) are the improvements from pre- to posttest among groups different? When performing these comparisons, careful attention was paid to the sample size of each group. This is particularly important because the group that completed Computer Cartography and Introduction to GIS, either sequentially or concurrently, has a relatively small sample size, and thus findings from these two groups might be restricted.

Table 5. A comparison of pre- and posttest scores by group.

	N	Pretest		Posttest		Score Difference
		Mean	S.D.	Mean	S.D.	
Control	35	11.171	5.046	11.714	4.773	0.542
Cartography only	18	12.972	5.829	14.111	4.629	1.138
GIS only	17	12.500	5.172	14.970	4.777	2.470*
Cartography and GIS						
Sequentially	7	17.571*	3.194	19.000	2.449	1.428
Concurrently	3	12.333	5.276	13.833	4.963	1.200

* $p < .05$.

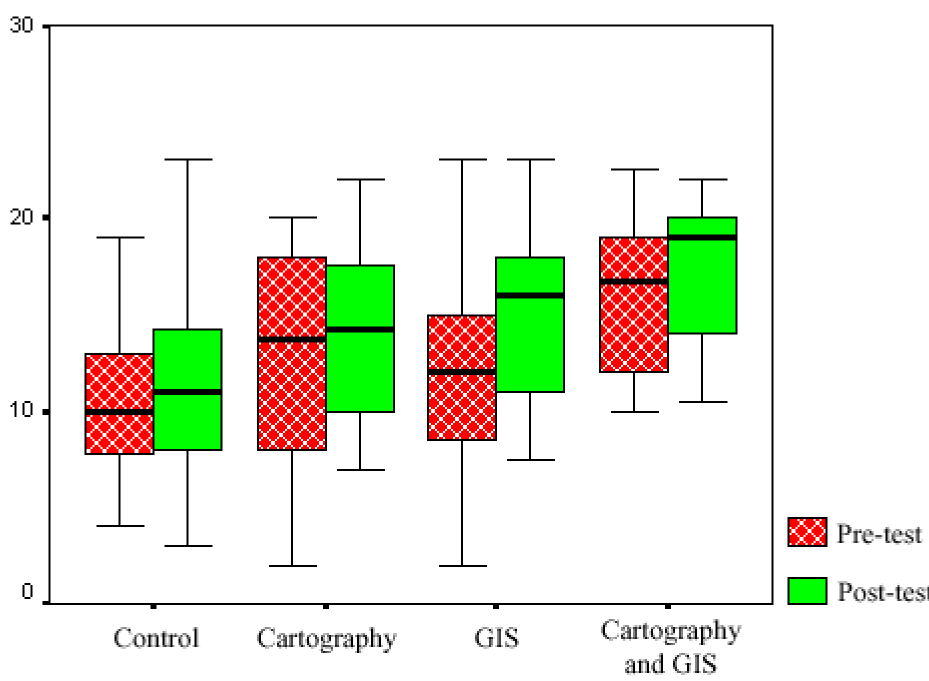


Fig. 5. A comparison of pre- and posttest scores by group.

By comparing pretest scores between groups, this study was able to determine students' spatial abilities prior to the treatment (GIS learning). When applying analysis of variance (ANOVA) to the pretest scores of the four groups (excluding the group that had only three subjects) significant differences were found (p = .032) (Table 6). A *post-hoc* comparison (using Tukey method) was used to determine which groups were significantly different from the control group and which were not. *Post-hoc* comparisons indicated that students who completed the cartography and GIS courses sequentially scored significantly higher than students of the control group (p = .019). This result should not be surprising because these students were the only group exposed to Computer Cartography prior to the treatment. No other significant differences between these groups were found.

Table 6. ANOVA for pretest scores by group.

	SS	*df*	MSE	*F*	*p*
Between groups	245.747	3	81.916	3.094	.032
Within groups	1932.922	73	26.478		
Total	2178.669	76			

All groups changed their scores during the experimental period. Analysis of covariance (ANCOVA) was used to determine whether there were significant differences in score improvements between groups (Table 7). ANCOVA was applied to the posttest scores of the four different groups, using their pretest scores as covariate to account for initial differences in spatial abilities. After performing ANCOVA, the most significant effects were further analyzed by *post hoc* comparisons in order to identify differences between groups. The *F* statistic value of 3.697 ($p = .016$) showed that a significant difference existed between the posttest scores. The *post-hoc* comparison (using Bonferroni method) revealed that students that completed only the GIS course improved their scores far more than the control group students ($p = .016$). This finding indicated that completion of a GIS course is relevant for improving students' spatial abilities. No significant difference, however, was found between the cartography group and the control group ($p = .992$).

Table 7. ANCOVA using posttest scores as the dependent variable with the pretest scores as the covariate.

	SS	*df*	MSE	*F*	*p*
Between groups	74.954	3	24.985	3.697	.016
Within groups	486.629	72	6.759		
Total	1905.130	76			

A *t-test* comparing paired sample scores between pre- and posttest within a group produced comparable results (Table 8). The students who completed only the GIS course increased their scores significantly as a result of the treatment ($p = .002$). Even though students who completed the cartography course only and both courses sequentially had higher scores on the posttests, their increases were not statistically significant ($p = .153$ and $p = .180$ respectively). It should be noted that students who completed both courses sequentially were closer to the maximum potential on the pretest. Consequently, it was more difficult for them to increase their scores on the posttest. The maximum score for both pre- and posttest was 24.

Table 8. Paired sample *t-test* for gain scores.

Group	Mean (posttest – pretest)	S.D.	S.E.	*t*	*p*
Control	0.5429	2.893	0.489	1.110	.275
Cartography only	1.1389	3.225	0.760	1.498	.153
GIS only	2.4706	2.741	0.664	3.716	.002
Carto. and GIS sequentially	1.4286	2.490	0.941	1.518	.180

In order to determine whether some items had a larger impact than others on the average difference between the control (N=35) and GIS group (N=27), the average scores between the two groups were compared item by item. A total of 14 question items were grouped into seven item types. Average scores for each group of students, displayed by item type are shown in Table 9. Significant differences in score changes across the item types were reported by ANCOVA statistics. Note that GIS users increased their scores more than the control group students on item types #2, #5, and #7 (Table 9). From this one can conclude that completion of a GIS course helps students in (1) finding the best location under various spatial conditions, (2) connecting regions having spatial correlations, and (3) identifying spatial information as point, line, or polygon.

Score increases from pre- to posttest in the control group in some item types (e.g., #1, #6, and #7) might have been caused by two major factors. First, it was not known to what extent having previously taken a similar test may have influenced a person's performance of the retest. Practice with test materials themselves (e.g., verbal analogies) would likely improve the performance of some students (Walsh and Betz 2001). Second, differences in the degree of difficulty from pre- to posttest may have contributed to score variations. The decreases in scores on item type #4 from pre- to posttest by both groups could have resulted from a more difficult posttest item. The problem of uneven item difficulty could be solved by conducting ANCOVA, which is able to detect comparable improvements by adjusting for preexisting differences by using the pretest as a covariate.

Table 9. Average scores and standard deviations by item type.

Item Types		Pretest		Posttest		Score Difference	*p* *(ANCOVA)*
		Mean	S.D.	Mean	S.D.		
Type 1: Map overlay operation (4)	Control	2.11	1.60	2.77	0.94	0.657	.623
	GIS	2.62	1.49	2.85	1.09	0.222	
Type 2: Finding the best locations (2)	Control	1.25	0.98	1.52	0.87	0.285	.025
	GIS	1.18	1.00	1.92	0.38	0.740	
Type 3: Orienting to real world frame of reference (3)	Control	0.94	1.50	1.11	1.32	0.171	.226
	GIS	0.72	1.05	1.44	1.34	0.722	
Type 4: imagining maps from verbal description (2)	Control	1.54	0.74	1.45	0.65	-0.085	.309
	GIS	1.66	0.62	1.62	0.49	-0.037	
Type 5: Identifying spatial correlation (5)	Control	1.85	1.35	1.45	1.40	-0.400	.022
	GIS	2.51	1.55	2.66	1.75	0.148	
Type 6: Creating a contour map (5)	Control	1.97	1.68	2.51	1.86	0.542	.198
	GIS	3.33	1.54	3.96	1.34	0.629	
Type 7: Identifying spatial data types (3)	Control	1.48	0.98	0.85	0.64	-0.628	.005
	GIS	1.74	1.12	1.40	0.74	-0.333	
Average	Control	11.17	5.04	11.71	4.77	0.542	
	GIS	13.79	4.97	15.88	4.54	2.092	

Completion of a physical geography course was also believed to have a positive impact on the students' spatial ability. The course on Physical Geography offered by geography department of Texas A&M University consists of both lectures and laboratory exercises. The course covers a wide array of topics such as climatology, biogeography, and geomorphology. Ten laboratory exercises are designed to provide students with hands-on experiences including measuring solar energy, interpreting topographic maps, drawing contour maps, calculating water budgets, examining tree ring sequences and analyzing hydrological systems. The effects of the Physical Geography course were investigated with the control group involving a total of 35 students (Table 10). During the treatment period, 16 students (out of 35) completed Physical Geography and 19 were not enrolled in the course. No significant difference between the two groups was found (p = .627). In fact, students who did not take physical geography improved more than students who did although the difference was not significant (p = .627).

Table 10. Effect of the completion of Physical Geography on the spatial skills test.

	N	Pretest		Posttest		Score Difference
		Mean	S.D.	Mean	S.D.	
Students who took Physical Geography	16	11.375	4.503	11.625	4.303	0.250
Students who did not take Physical Geography	19	11.000	5.580	11.789	5.252	0.789

Score Comparison by Gender and Major

The second objective of this study was to determine if gender or academic major affected the students' performance on the spatial skills test. Fig. 6 and Table 11 summarize the average scores in the pre- and posttest and their distribution by gender. Male students did score significantly higher than females on both the pre- and posttest (p = .018 and .019 respectively), although females improved more. The improvement pattern of female students is more irregular, while males show a more uniform pattern between pre- and posttest. Three (of eight) female students showed improvements much higher than the other female students (Fig. 6).

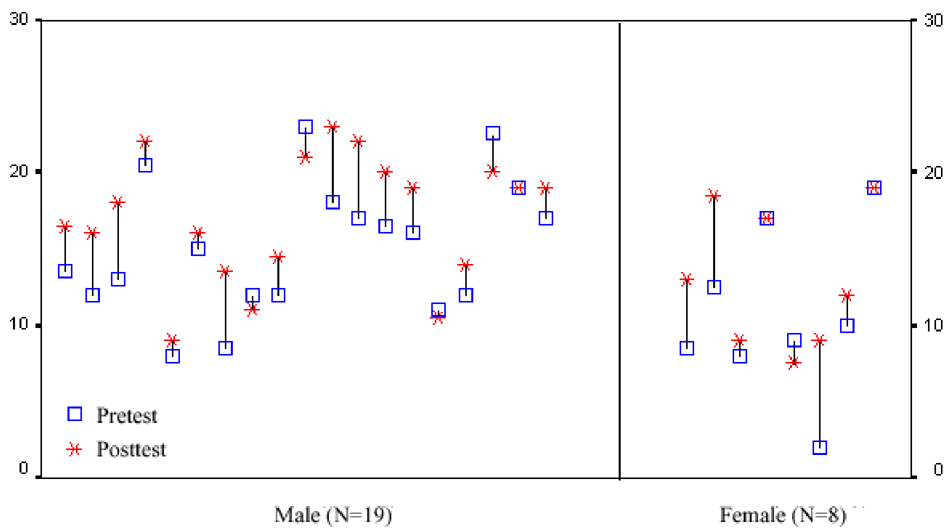


Fig. 6. Score changes of pre- and posttest by gender.

Table 11. A comparison of pre- and posttest scores by gender.

	N	Pretest		Posttest		Score Difference	*p* *(paired sample t-test)*
		Mean	S.D.	Mean	S.D.		
Male	19	15.079	4.321	17.053	4.116	1.974	.001
Female	8	10.750	5.385	13.125	4.557	2.375	.034

A *t-test* comparing paired sample scores between pre- and posttest within a group showed that both males and females increased their spatial ability significantly (Table 11). Since there were differences prior to treatment, ANCOVA was applied to determine whether they were significantly different for improving scores between groups. ANCOVA revealed that there was no significant difference in score improvement between the two genders (*p* = .571) (Table 12). This finding indicates that male and females students benefit similarly from completing a GIS course.

Table 12. ANCOVA using posttest scores as the dependent variable with the pretest scores as the covariate (by gender).

	SS	*df*	MSE	*F*	*p*
Between groups	1.906	1	1.906	.330	.571
Within groups	138.654	24	5.777		
Total	537.167	26			

The performance by students having different academic majors was also compared. The 27 students who completed the GIS course were grouped into three categories: geography, science and engineering, and humanities. The humanities group was excluded from further study because it had only 1 student. The average scores of geography majors and science and engineering majors were compared and are shown in Table 13. Average score changes from pre- to posttest by major are displayed in Fig. 7. The relatively higher standard deviations in test scores by students majoring in science and engineering, a grouping of students majoring in several science and engineering disciplines, most likely reflected their various fields of study (Table 13).

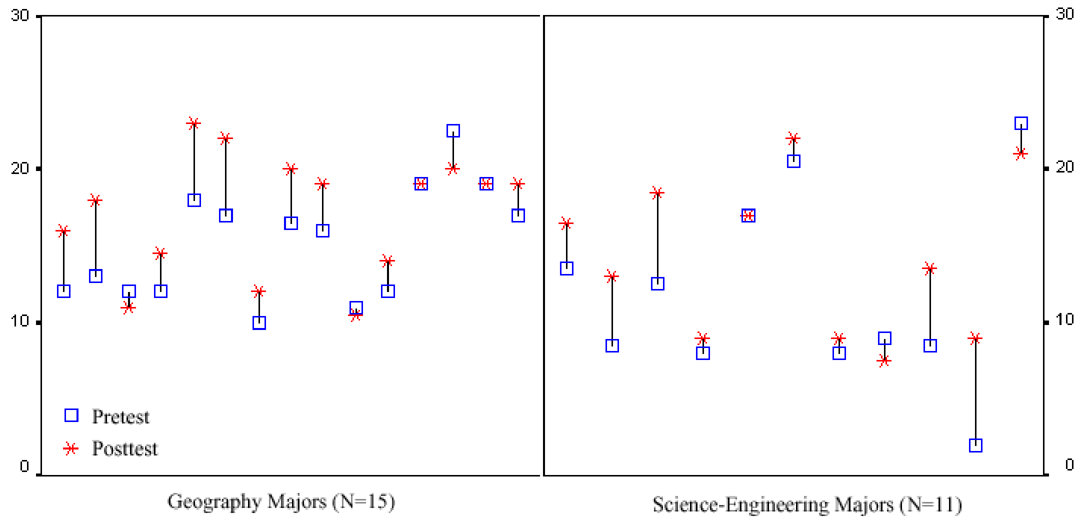


Fig. 7. Score changes in pre- and posttest by major.

Table 13. A comparison of pre- and posttest scores by major.

	N	Pretest		Posttest		Score Difference	*p (paired sample t-test)*
		Mean	S.D.	Mean	S.D.		
Geography major	15	15.133	3.676	17.133	3.920	2.000	.003
Science and engineering major	11	11.863	6.212	14.181	5.163	2.318	.015

Geography majors scored higher on the pre- and posttest than science and engineering majors, but the difference was not significant (p = .053 and .055 respectively). Analysis of paired sample *t-test* for pre- and posttests showed that students of both groups increased their scores significantly after completing a GIS course (Table 13). ANCOVA was conducted to determine whether the scale of the score improvement was significantly different between the two groups (Table 14) but revealed no significant differences in score improvement between the two groups of students (p = .683). These results indicated that both groups of students benefited comparably from the completion of the GIS course. It must be noted that, given the small sample size for each gender and major, the results should be interpreted with caution.

Table 14. ANCOVA using posttest scores as the dependent variable and the pretest scores as the covariate (by major).

	SS	*df*	MSE	*F*	*p*
Between groups	1.033	1	1.033	.171	.683
Within groups	138.795	23	6.035		
Total	537.154	25			

Correlation between the Spatial Skills Test and GIS Course Achievement

Students' performance in the spatial skills test was also correlated with each of their scores in the GIS course: lab exercise score, mid-term grade, and final exam grade. The results of these correlations are summarized in Table 15. It was expected that (1) positive correlations between students' spatial ability and performance in the GIS course would exist; and furthermore, (2) lab exercise scores, which demanded intensive spatial cognitive processes, would have a stronger correlation with the spatial ability scores than exams.

These expectations were only partially supported by empirical findings. Relatively strong correlations were found between the two spatial skills tests and the final exam score [.443 (p = .027) and .329 (p = .108)] and between the two spatial skills tests and lab exercise score [.357 (p = .080) and .405 (p = .044)]. However, correlations with the mid term scores were weak [.185 (p = .377) and .213 (p = .307)] most likely because this exam occurred before much lab work was done. There was no significant difference in the correlations between the spatial skills test and either the final exam or the lab exercise scores.

Table 15. Correlation between spatial skills test and performance of GIS course.

	Pretest	Posttest	Mid-term	Final exam	Lab exercise
Pretest	1	.852 (*p*=.000)	.185 (*p*=.377)	.443 (*p*=.027)	.357 (*p*=.080)
Posttest	.852 (*p*=.000)	1	.213 (*p*=.307)	.329 (*p*=.108)	.405 (*p*=.044)

In addition to these correlations, the impact of the final assignment type on the spatial skills test was examined, since students of the GIS course were asked to complete either a project or a paper as their final assignment. During the semester, 17 students chose a paper assignment and seven students a project assignment. Table 16 shows the pre- and posttest scores of the two groups. It was expected that students who completed a GIS project would show higher improvement in spatial ability, since paper assignments focused more on theoretical aspects of GIS rather than spatial analytical or visual skills.

Table 16. A comparison of pre- and posttest scores by assignment type.

	N	Pretest		Posttest		Score Difference	*p (paired sample t-test)*
		Mean	S.D.	Mean	S.D.		
Paper	17	14.205	5.049	15.676	4.260	1.470	.012
Project	7	11.857	5.459	14.214	4.724	2.357	.032

A comparison of paired sample *t-test* scores between pre- and posttest within each group showed that in both cases students increased their spatial ability significantly (Table 16). The students who selected to do a project did improve their scores by a greater amount than students who wrote a paper. Because the sample sizes are small, however, the difference in the score improvement from pre- to posttest between the two groups of students taking different assignment types was not significant (p = .778) (Table 17).

Table 17. ANCOVA using posttest scores as the dependent variable and the pretest scores as the covariate (by assignment type).

	SS	*df*	MSE	*F*	*p*
Between groups	.385	1	.385	.081	.778
Within groups	99.606	21	4.743		
Total	435.000				

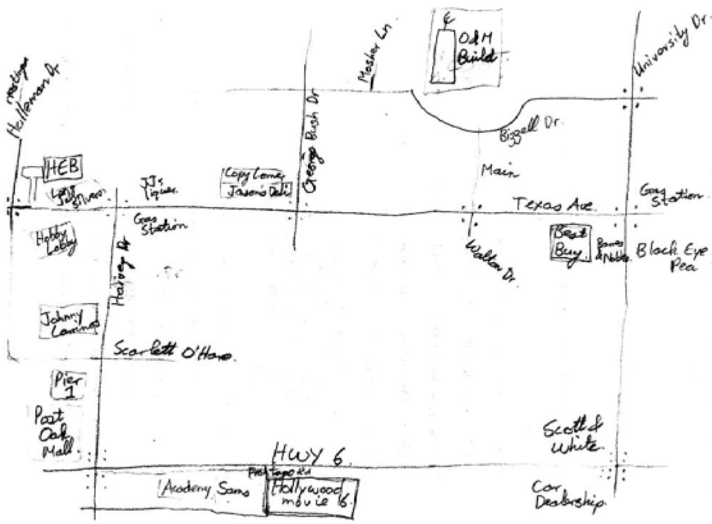
Experiment 2: Cognitive-Mapping Test

Video-Analysis of Map-drawing Strategy

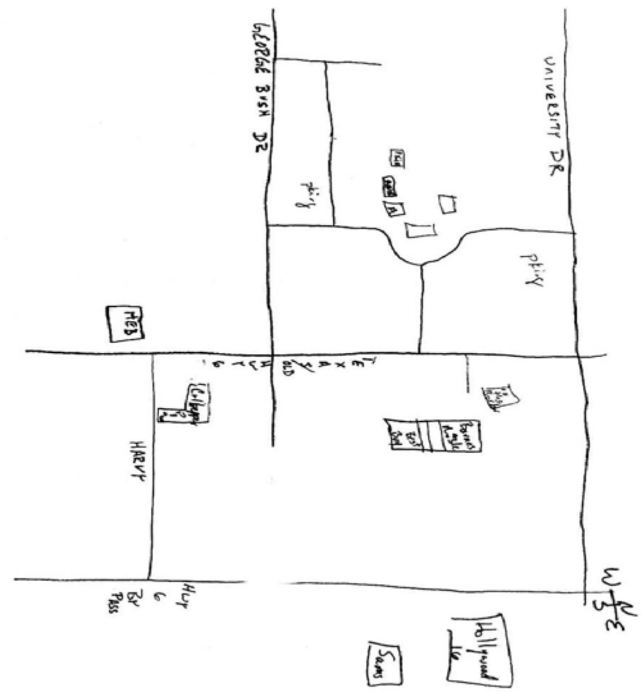
Videotaping the participants' map-drawing process allowed for the analysis of map-drawing strategies employed by the subjects, including the sequence of map construction. *Post-hoc* analysis of the finalized hand-made maps could not have provided the same amount and types of information. For example, the two maps shown in Fig. 8, produced by students in this experiment look similar and both might have been classified as survey maps (according to Applyard 1970), but the analysis of the map-drawing process revealed that the maps were constructed using completely different strategies. This finding seems counter to that of Foley and Cohen (1984) who assert that different strategies lead to radically different results.

This study suggests, and demonstrates the efficacy of, a method to accurately identify the cognitive mapping strategies of individuals. If, as many researchers have argued, mapping strategies reveal information about the cognitive processes people use to operate in their environment, it is imperative that researchers categorize the strategies correctly. Past research has relied on evaluation of the (finished) maps produced by individuals to identify mapping strategies. Unfortunately, as this study demonstrates, it is often extremely difficult to determine a subject's strategy from the map she or he draws. Videotaping subjects while they map does add time and effort to the experimental design, but modern digital video equipment is affordable enough that researchers can employ more than one camera during mapping sessions, reducing the time necessary to collect data. In addition, digital images can be viewed repeatedly, allowing researchers to extract detailed information that might otherwise go unobserved. Finally, digital motion pictures are easily edited so that compelling presentations demonstrating the results of the research can be developed and shown to other researchers.

The inability to determine a subject's mapping strategy from a finished map also means that it is often impossible to detect changes in a subject's mapping strategy over time. The pilot test demonstrated that some subjects changed their map-drawing strategy after the completion of a computer cartography course. Only through the analysis of tapes of subject's map-drawing process, was it possible to detect these changes.



A



B

Fig. 8. Maps created based in a regional (A) and a hierarchical (B) approach.

Classification of Map-drawing Strategy

Based on the 64 video tape segments of the subjects constructing sketch maps for the pretest, the subjects' strategies were classified as hierarchical, regional, or mixed. The strategies were classified as hierarchical if subjects drew the main roads across the entire map first. Students who used the hierarchical strategy exhibited two variations of the strategy. One sub-group constructed their sketch maps by drawing almost all of the primary and secondary roads before they located any targets. This strategy was termed "hierarchical 1" (H1). An example of the H1 strategy is displayed in Fig. 9. A second sub-group of students used a variation of this strategy. After drawing the main roads, these subjects drew one or two secondary roads in order to locate a target. Then they mapped one or two more secondary roads to locate another target, repeating the process until they completed the map. This multiple-stage strategy was termed "hierarchical 2" (H2) and is displayed in Fig. 10. The strategies were categorized as regional if subjects did not draw main roads across the entire map, but instead mapped one sub-area before moving on to another sub-area. See Fig. 11 for an example of a map constructed using the regional strategy. Finally, some students used a strategy that combined elements of both the hierarchical and regional strategies. This strategy was labeled "mixed." An example of this strategy is displayed in Fig. 12.

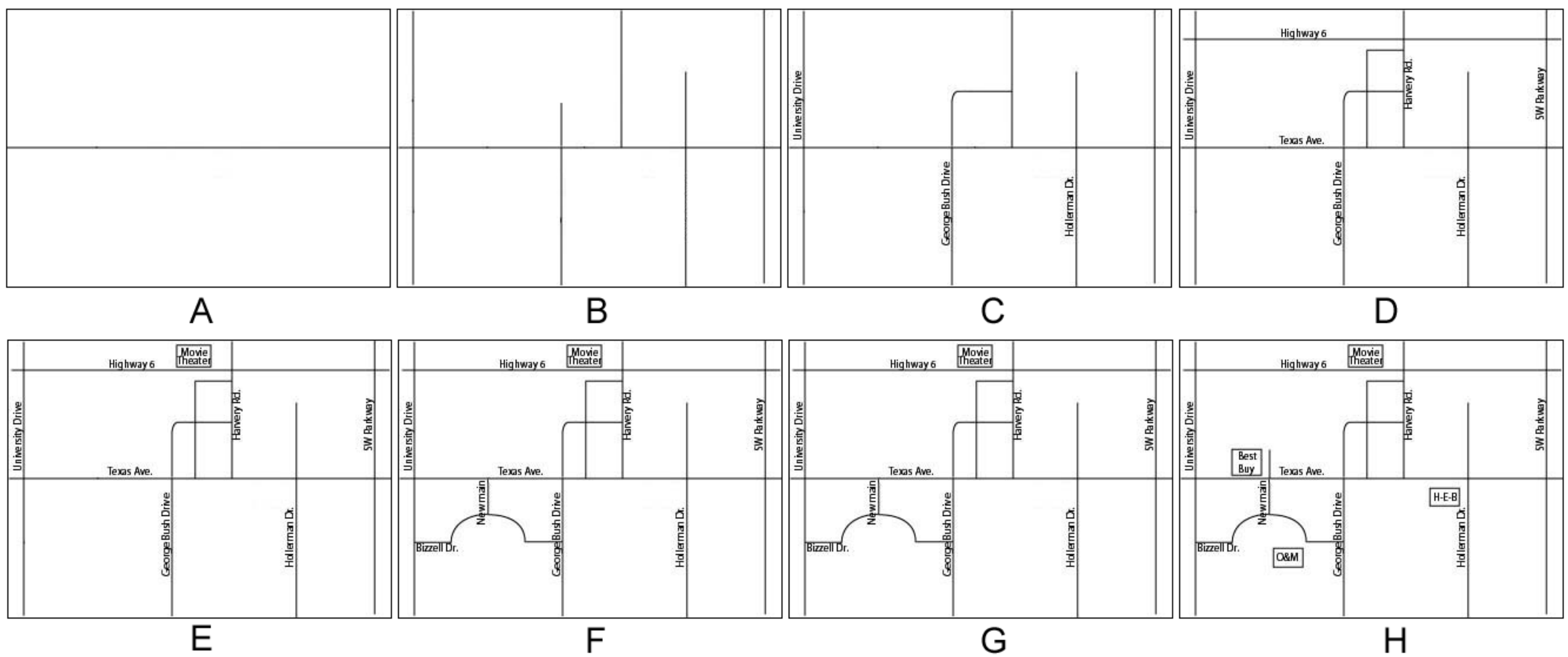


Fig. 9. Hierarchical approach 1 (major and secondary roads drawn before features).

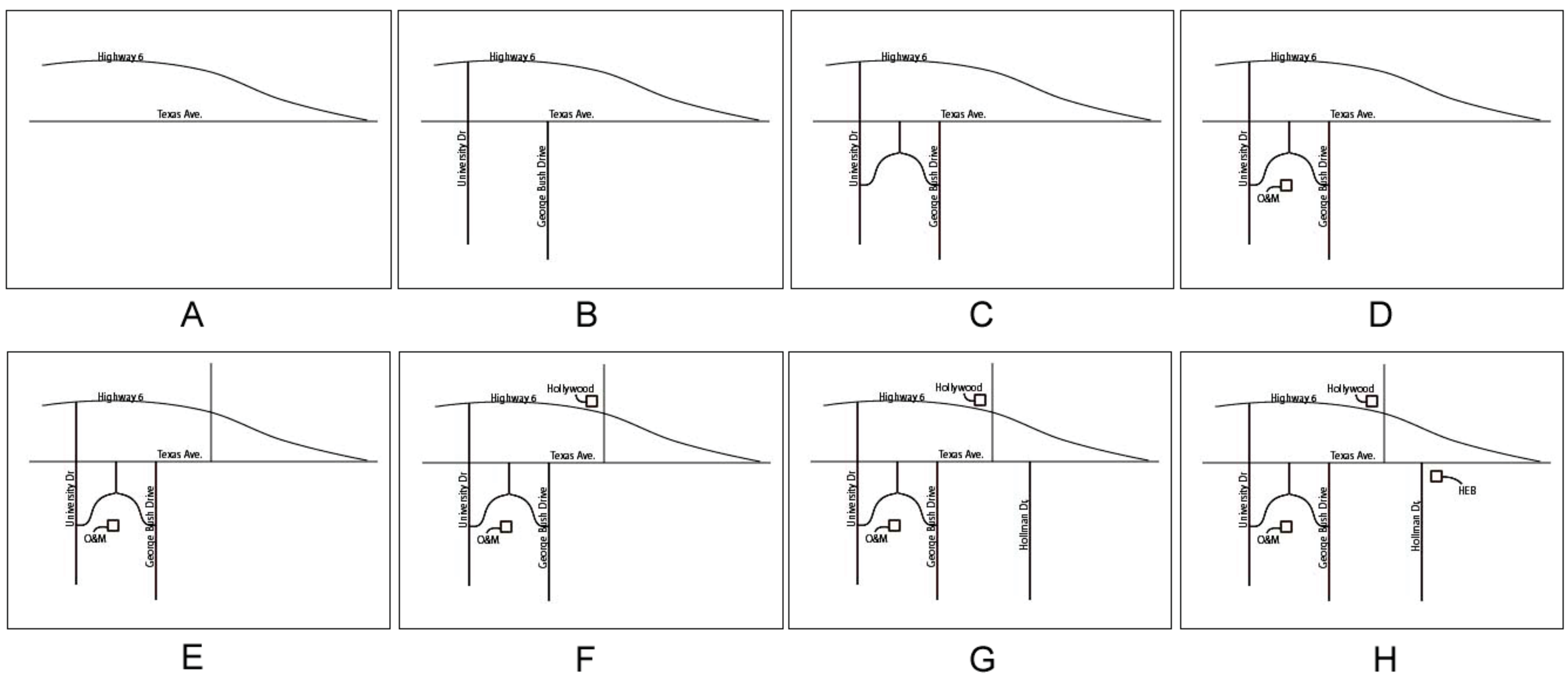


Fig. 10. Hierarchical approach 2 (major roads first, then each secondary road and associated features).

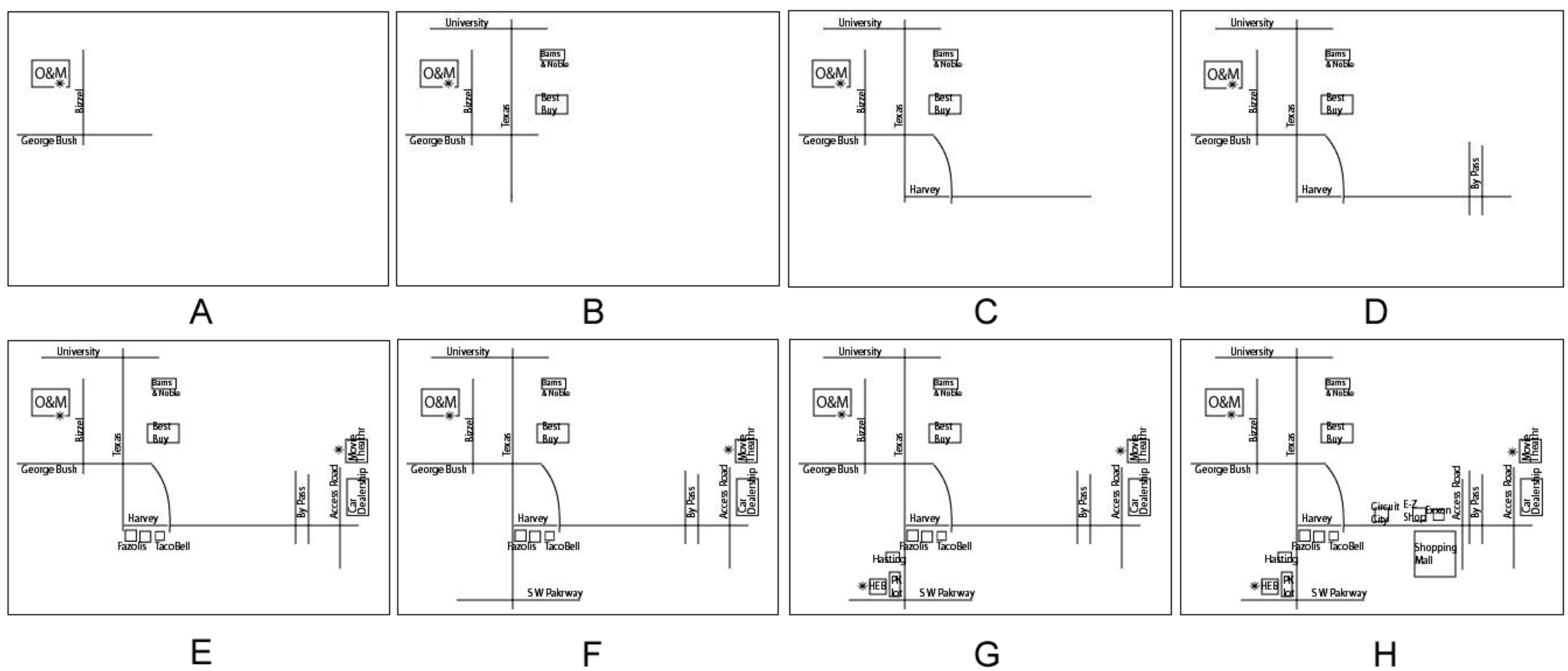


Fig. 11. Regional approach (one area at a time, without a major road network).

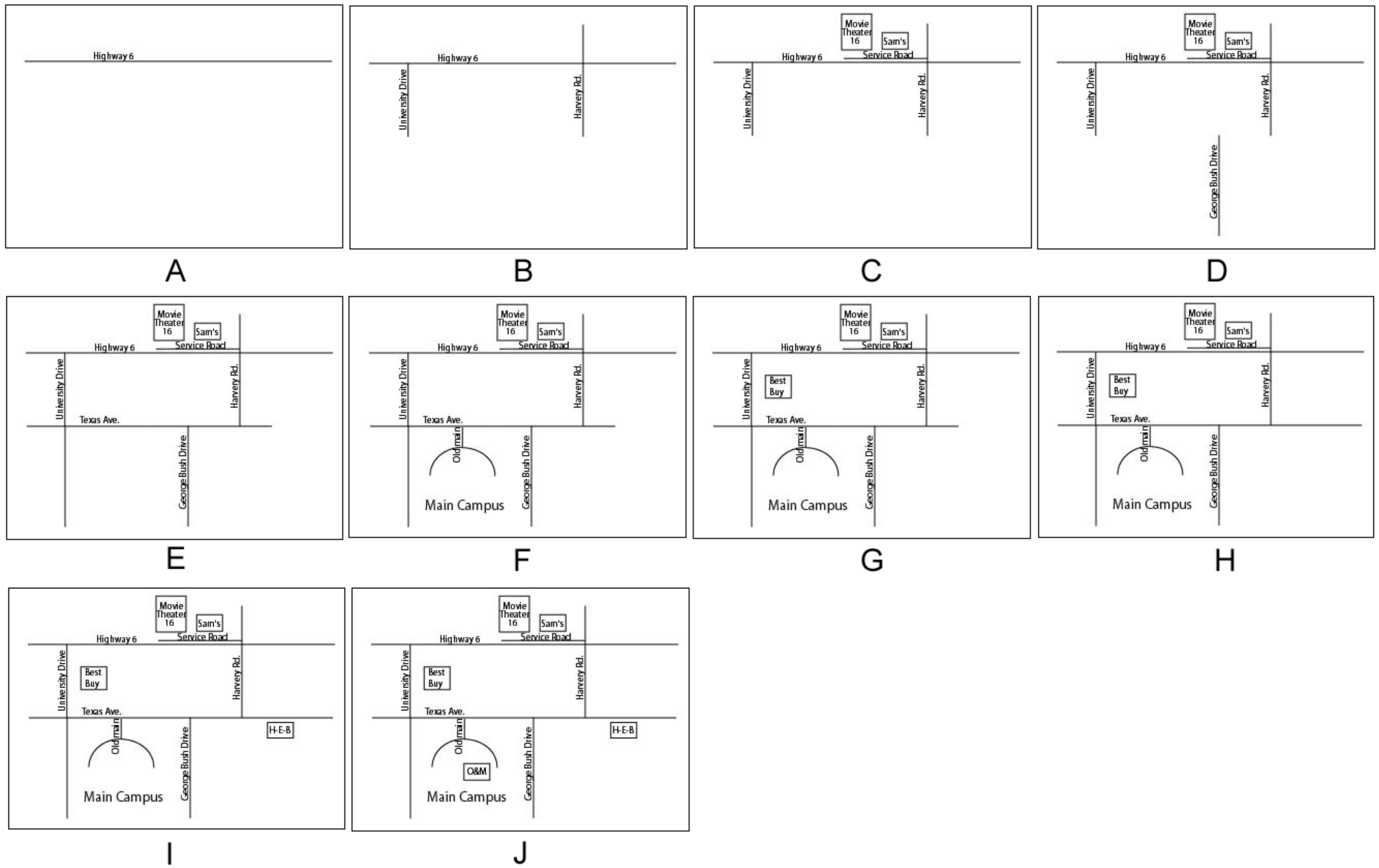


Fig. 12. Mixed approach.

The majority of the subjects (47 of 64) used one of the hierarchical strategies. The H2 strategy was the most frequently observed. It is very similar to the strategy described by Taylor and Tversky (1992) who reported that when subjects were asked to describe their cognitive maps verbally, they began their maps with larger border features, continued with the major roads, and then placed the smallest features, the buildings. It seems obvious that one or two main roads constructed at an early stage could serve as a reference point for the location of other places. Thus, the relationship between main roads and details (secondary roads) can be understood as a function of hierarchy. Excerpts of three typical transcripts from students using the H2 strategy illustrated the multiple-stage process that characterizes this mapping strategy:

> I drew Highway 6 first and then I drew the bypass and Texas Avenue. Those are the main roads that go through the town. I related everything else off those two roads. I started drawing the next level roads down, which is the next main highway in the area that was discussed, which is Highway 30, also known as Harvey (road). I drew the movie theater next it was… And I drew George Bush (Drive), which is the next main road needed to relate where the O&M building was. And I drew Bizzell connecting it.
>
> I drew Highway 6 first because this is one of main highways where most people come in off of. Then I drew Texas (Ave.), another pretty much main road through College Station. University (Drive) runs along the campus as well as George Bush (Drive). Harvey road, which can take you to Sam's and Hollywood movie…. Then Holleman (Drive), that's connected to HEB. I drew New Main (road), which runs close to the O&M building. And I drew the feeder of Highway 6 running through Hollywood Movie.
>
> I drew Texas Ave. first because I feel like that it's the most major road in town. And the BestBuy and HEB are off that road. And then …by drawing Texas Ave. I could add … the other major roads in town …off that way I can find out where the school is. Because I know on all four sides of the school there are major roads. When I have the major roads in town, I could draw the small roads of the university … then I could label the O&M building. … I drew Highway 6 because that's where the movie theater is off. So basically I drew the major roads in town first. … I think (Farm to Market Road) 2818's right there. Now it's like a skeleton

> of the city. … That was Holleman (Drive). I knew that HEB is next Holleman. So, BestBuy… right off Texas (Ave).

In contrast to those who used the H2 strategy, subjects who used the H1 strategy mapped almost all of the roads before they placed any target monuments. This strategy represents the most stereotypically hierarchical strategy used by any of the subjects. The students who used the H1 strategy seemed to have more flexible and precise knowledge of the area than other subjects. The following is an excerpt of a typical transcript from a student using the H1 strategy:

> Anytime I think about the city I kind of think outskirts first and kind of work in. … If you start inside, you might be too detailed. … I tried to have some scale, obviously not much. I think that starting inside, all of a sudden you've got all this junk packed in, and then you know you have stuff way off the page. … If I put the roads in the first, I can better reference where the stuff is. If I put the stuff in and it gets off at the first, the whole image after while is gonna get…

By drawing one or two major roads first, using the H1 and H2 strategies, students could reduce the load on their working memory. The H1 and H2 strategies also provide physical limitations on the range of potential drawing and consequently reduce the size of the search space to be considered. However, since the H1 strategy requires a longer planning horizon and a more systematic sequence of drawing, this strategy can be regarded as more plan-based than the H2 strategy.

Most students who used the regional strategy (5 of 7) began by drawing the O&M building which is where the subjects were physically located when they were drawing their maps. The subjects gave a variety of reasons for beginning their sketch maps with the O&M Building or the campus:

> I started with the O&M building because I'm familiar with this area.

> Probably because that's where I am at.
>
> I liked to know where the campus is because it seems like everything is related to where the campus is... Kyle Field is a pretty good landmark here. Coming into College Station if you don't know where you going. If you see that then you know where you're at. I drew that first I guess.
>
> I drew A&M (campus) first because that's the center piece to me. It is kind of base, everything around where it is in relation to A&M … That (campus) is really the first thing came into my head. (I) drew (campus) first and drew roads around it. There wasn't really a specific reason. It seems the easiest for me to do it that way.

From the content of these interviews, it appears that participants using the regional strategy begin by drawing important or familiar targets first. One of these participants gave a different reason for beginning at one corner:

> I started with the O&M building because it was just the first one in the list (of targets students were asked to locate). So I went systematically through it (list of targets). Kind of went in that order.

Whereas participants with other strategies completed a major road by one stroke, those using the regional strategy constructed major roads segment by segment. The following two excerpts give an idea of why they did not draw a road with a single stroke, and were taken from answers to the questions: why didn't you complete Texas Ave. all at once? Why did you draw only half of University Drive?

> Because I was trying not to forget anything on the way. So I was thinking. You know, up to a point like did I forget anything or how far am I going to have to go to include everything.
>
> Because I didn't know how far down I was going to have Texas Ave., because nothing is to scale. That's why I didn't draw all University (Drive).

In addition, participants with the regional strategy encoded the area as a set of sub-regions occupying geometrical divisions of the map such as the top half, bottom left quadrant, etc. There are two plausible explanations for this type of drawing pattern. One is that starting at the upper-left corner may be related to habits of reading order, that is, top-down, left-right (Kugelmass and Lieblich 1979). The other is that problem solving based on the spatial proximity of elements in the task is more often observed in novices than in experts who focus more on the functional nature of the elements in the task (Egan and Schwartz 1979). Just as local maximization can lead to global non-optimality, localized map-drawing might not be globally optimal (Anderson 1991).

Some of the participants using the regional strategy drew and explained their maps as if they were driving around the area:

> Then the shopping center and on the other side of Texas (Ave.) ... kind of like, if I was driving down Texas (Ave.), kind of what I see to the left of me.
>
> I think that it's because I am from Fort Worth and that's the direction I come in. So that's just what I think of what I know I'm going to pass, I guess that's how I normally see it.

This strategy may be related to the "mental tour" suggested by Linde and Labov (1975) and Levelt (1982). According to them, when people describe an apartment, for example, some of them start at the front door and then imagine moving through the apartment room by room.

Even though users of the regional strategy frequently started drawing in a corner of the paper without constructing a framework for the entire area, most of them seem to envision the whole map from the beginning:

> Definitely I thought about it (layout) in my head before I drew it.
>
> It's like all already there in my brain, I just have to start somewhere. … I knew that I had to fit in Hollywood 16 (movie theater) eventually. So I need space in bottom left and corner. That's why I picked that top right corner relative to

bottom left corner leaving space available for the Hollywood 16.

> I tried to keep in mind where the full extent of the map would have to be because all the way on the right, you'll see that, it has Hollywood 16 (movie theater). I knew that would have to be on the right. And I knew Best Buy, HEB, so I just kind of kept those in mind where those were. Make sure that all those were included on the side.

The mixed strategy was similar to the hierarchical strategy in that subjects began by drawing the main roads. The mixed strategy, however, also displays similarities with the regional strategy in that subjects completed a sub-area or half of the map before they moved to another area.

Quantitative Comparison among Strategies

Variability among strategies could result from the different spatial cognitive ability of mappers. For example, the regional strategy is thought to be a bottom-up approach more frequently used by novices (Chase and Chi 1981; Chi et al. 1981). However, the qualitative data provided by the interviews did not support this argument. Subjects of both strategies have a similar grasp of the spatial details of the study area. One difference between the hierarchical mappers and the regional mappers is that the subjects using the hierarchical strategy seem to draw their maps more efficiently. This difference is illustrated by the mean time these two groups took to draw their maps. The average time to construct maps for all students was 361s. The mean time for users of the hierarchical strategies was 343s; for the users of the regional strategy was 478s. The difference was significant (p = .043).

Table 18. The mean second required for each map-drawing strategy used by the subjects (pretest only).

	Hierarchical strategy (73%)		Mixed strategy (16%)	Regional strategy (11%)
	H1	H2		
N	9	38	9	8
Seconds required (S.D.)	343 (170)		351 (100)	478 (174)

Map-drawing strategies were compared for specific subdivisions within the population: males vs. females and geography majors vs. science and engineering majors vs. humanities major. Overall, there were no significant differences in students' choice of map-drawing strategies between male and female students– the proportion using each of the map-drawing strategies in each gender group was comparable (Table 19). This finding agrees with research by Bruin et al. (2000) and Cochran and Wheatley (1989), who did not find significant gender differences in strategies used on spatial skills tests. Similarly, academic major did not make a significant difference when choosing map-drawing strategies (Table 19).

Table 19. Map-drawing strategy by gender and major (pretest only).

		Gender		Major		
		Male	Female	Geography	Science and Engineering	Humanities
Hierarchical strategy	H1	6 (16%)	3 (12%)	5 (14%)	3 (15%)	1 (14%)
	H2	21 (55%)	16 (64%)	22 (61%)	11 (55%)	4 (58%)
Regional strategy		6 (16%)	3 (12%)	5 (14%)	3 (15%)	1 (14%)
Mixed strategy		5 (13%)	3 (12%)	4 (11%)	3 (15%)	1 (14%)
Total		38	25	36	20	7

Changes of Map-drawing Strategies

After finishing either the GIS or cartography course, the participants produced their second maps. A total of 46 students completed both the pre- and posttest of the cognitive-mapping experiment. Table 20 and 21 show which strategies were used by participants during the pre- and posttest, and how their strategies changed after completion of either the GIS or cartography courses.

Forty one percent of the students (19 of 46) changed their map-drawing strategies for the posttest. It was assumed that learning GIS would cause students to change their map-drawing strategies from regional to hierarchical, from mixed to hierarchical or from hierarchical 2 to hierarchical 1. Ten of 13 changes observed within the GIS group supported this research assumption. However, the same pattern was not found in the group that completed only the cartography course; only three of six changes in the cartography group agreed with this research assumption (Table 21).

Table 20. Map-drawing strategies in the pre- and posttest.

		Hierarchical strategy		Mixed strategy	Regional strategy
		H1	H2		
Cartography	Pretest	3	10	1	3
	Posttest	1	11	1	4
GIS	Pretest	3	15	4	3
	Posttest	6	14	3	2
Cartography and GIS	Pretest	2	2		
	Posttest	4			

Table 21. Direction of map-drawing strategy changes.

	Direction of map-drawing strategy changes	N
Cartography (6 of 17)	Hierarchical 1 to Regional	2
	Hierarchical 2 to Regional	1
	Hierarchical 2 to Hierarchical 1	1
	Regional to Hierarchical 1	2
GIS (11 of 25)	Hierarchical 1 to Hierarchical 2	1
	Hierarchical 2 to Hierarchical 1	3
	Hierarchical 2 to Mixed	1
	Hierarchical 2 to Regional	1
	Mixed to Hierarchical 2	3
	Regional to Hierarchical 1	1
	Regional to Mixed	1
Cartography and GIS (2 of 4)	Hierarchical 2 to Hierarchical 1	2

About half (11 of 19) of the participants who changed their map-drawing strategies were interviewed to investigate the underlying reasons for their strategy changes. The 11 students were randomly selected from either the GIS or the cartography group. The analysis of the interview data is presented jointly because there was no significant difference between the GIS and cartography group in terms of reasons for their strategy changes.

Interestingly enough, five of the 11 interviewed participants could not explain the reason they used different map-drawing strategies for their second maps:

> I have no idea. (A participant who changed from regional to H2)
>
> It's just… at the first time the campus popped up in my head first. But at the second time University Drive came up first. It's hard to explain that. (A participant who changed from regional to H2)
>
> I don't know. Maybe I was tired. (A participant who changed from H2 to

regional)

> It makes more sense to me to draw all at once. I am not sure why I drew two increments [segments] the first time. (A participant who changed from regional to mixed)

Even though the interval between pre- and posttest was relatively long (about three months), testing effects were found in some cases. Three (of the 11 interviewed participants) attributed changes in their map-drawing strategies to learning effects from their pretest:

> I just realized that I thought about the last time I did this. And I realized that I wasted a bunch of space I could use to put more details on. (A participant who changed from H1 to H2)

> I just think that I learned what I did wrong about the first one. (A participant who changed from H2 to mixed)

> I needed a lot more space. I realized that I've already drawn Texas Ave. first before I even thought about how much space I would need until… it was too late. … Because this time [posttest] I just wanted to make sure that I had enough space to get everything on that. I wanted to get my grid first. (A participant who changed from mixed to H2)

Only one student in the same group attributed the change in the map-drawing strategy to GIS experience:

> [GIS experience] …getting me to think like where things are compared to another places. At the beginning I had to do it like when I was moving in my car approaching something that's what I saw. The GIS course helped me see the big picture. (A participant who changed from regional to H1)

Even though the reasons that some participants used for adopting different strategies for their second maps were not clear, impacts of their GIS experience on map-drawing were easy to find during interviews. For example, some participants either added a north arrow or used different types of north arrows as orientation for their second maps:

> I think that I used to do this in class, GIS.
>
> From everything I read covered in all the classes… it should always have a north arrow.
>
> I guess that it's working with ArcView. It looked like that.
>
> I think from classes like… I learned more than one compass through GIS [class].
>
> I guess getting used to making more maps; you need to know where you oriented it… just kind of reference.

The influence of GIS courses was also found on space usage:

> Definitely in that [GIS] class one thing that it wants you [to do] is to use as much as area you can to show what you have. And I think that is probably why I drew a bigger space on this one here.

Remote sensing coursework also affected some students' viewpoints:

> I saw them [air photos] in remote sensing class. Because I see it from overhead, that's more how you draw a map.
>
> Looking from space, you know, satellites [images from remote sensing class] help you see holistically instead of what's right around O&M.

Relationship between Map-drawing Strategy and Spatial Ability

The relationship between students' map-drawing strategies and their performance on the spatial skills test was investigated, and the findings are summarized in Table 22. A total of 39 students finished both the spatial skills test and the cognitive-mapping test. They were grouped by type of strategy, and the average score of each map-drawing group was calculated. Contrary to expectations, students who used the regional strategy scored higher in the spatial skills test than those using either hierarchical or mixed strategies. However, the score difference between the four different strategies was not significant (p = .284). It should be emphasized that this insignificant difference may have been caused by the small sample size used in the study.

Table 22. A comparison of posttest scores by map-drawing strategies.

Strategy	N	Mean	S.D.
Hierarchical 1	6	16.666	2.750
Hierarchical 2	23	14.260	5.065
Mixed	6	16.250	4.535
Regional	4	19.875	1.887

Table 23. ANOVA for posttest scores by map-drawing strategies.

	SS	*df*	MSE	*F*	*p*
Between groups	80.062	3	26.687	1.316	.284
Within groups	750.389	37	20.281		
Total	830.451	40			

CHAPTER V

DISCUSSION AND CONCLUSIONS

This chapter provides interpretation of the results of the two previous research experiments and their discussion in the context of the research questions. The discussion also connects the findings of this study with the literature reviewed in Chapter II. This is followed by a summary and conclusions. The results of this study are discussed in the same order established when presenting the research questions. The research questions that were previously framed for this study are as follows:

1. Will GIS learning affect students' spatial ability?
    a. Will completion of a GIS course affect the spatial ability of college students? Will completion of a cartography course be equally effective as a GIS course?
    b. Will these effects be different for male and for female students? Will these effects differ by students' academic majors?
    c. Is there a relationship between students' spatial abilities and learning achievement in a GIS course?
2. Will GIS learning affect students' spatial problem solving?
    a. Will completion of a GIS course affect the map-drawing strategy of college students?
    b. Is there a relation between students' map-drawing strategies and spatial ability?

Research Question 1a

Will completion of a GIS course affect the spatial ability of college students? Will completion of a cartography course be equally effective as a GIS course? The significant increase in the spatial abilities of students that resulted from taking a GIS course was the most important finding in this study. ANCOVA statistics followed by *post hoc* testing indicated that a statistically significant difference existed between the group of students having completed a GIS course and the control group. The GIS group's scores improved more than those of the control group.

A major question that must be addressed is What is source of this improvement? Retesting, that is, repeating the spatial skills tests, may have had an influence students' improvement. However, since a comparable improvement was not found in the control group, it was assumed that the retesting effect was not significant. It was also noted that the participating students may have been exposed to other geography courses that could have had some influence on their spatial ability. This was especially true for Physical Geography, where students could develop basic geographic skills, especially during laboratory sessions. However, the performance of participants who had completed the Physical Geography course during the semester did not differ from students who did not take the course. Thus, this research concluded that the primary source of improvement was the completion of the GIS course.

The nature of this improvement can be illustrated by connecting what the students learned from the GIS course and what was assessed by the spatial skills test. Specific activities from the GIS course were connected to the three types of spatial abilities measured by the spatial skill test (Fig. 13). As can be seen in the Fig. 13, GIS activities have direct relationship with spatial abilities, especially spatial relations. Since the spatial skills test used for this study was focused on the spatial relations factor, an improvement in spatial ability of students studying GIS should be expected.

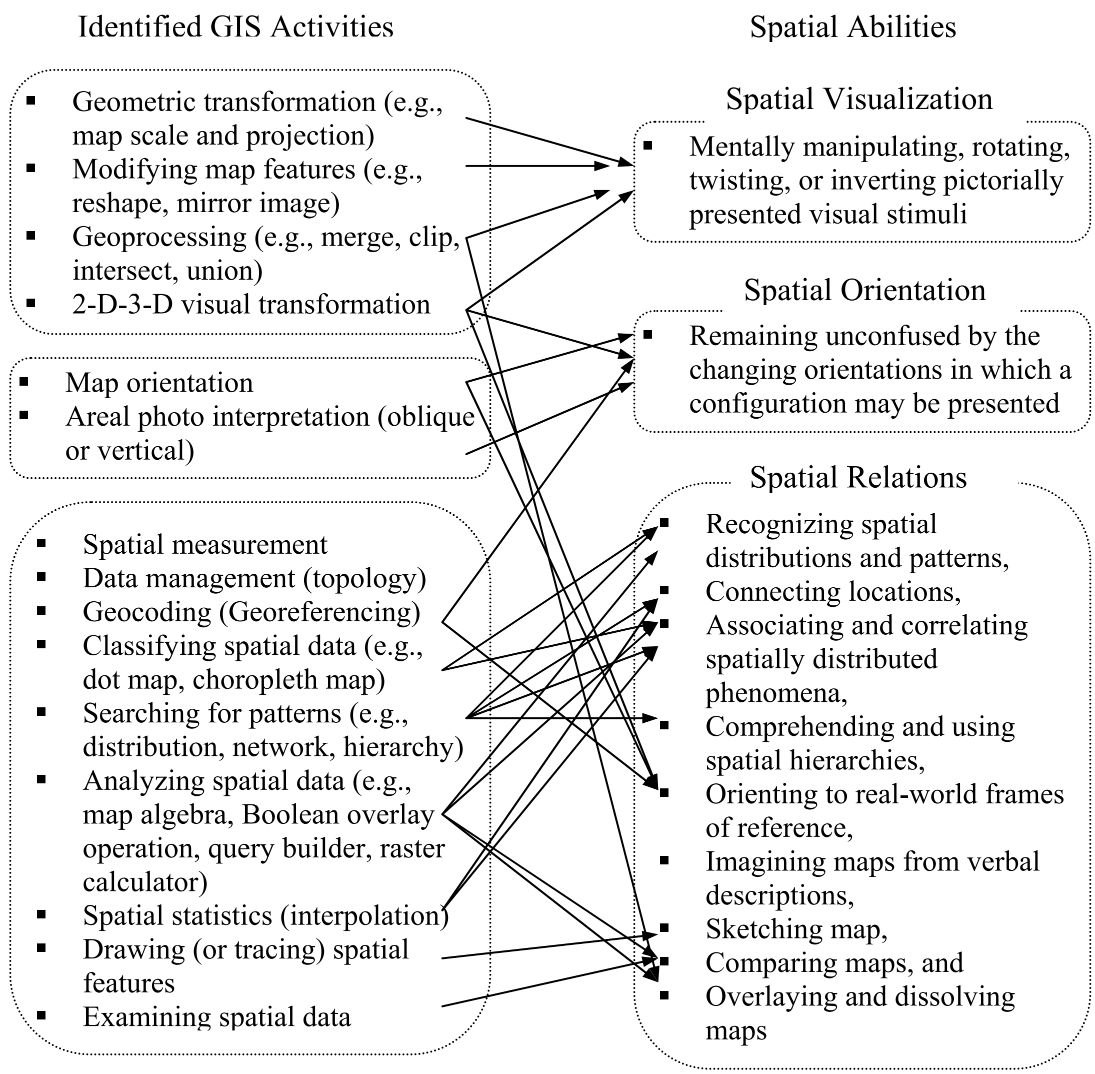


Fig. 13. Relationship between GIS activities and spatial abilities.

However, the strength and type of interaction between GIS learning and improvement of spatial abilities varied widely. Certain aspects of the interaction were more easily verified than others. For example, it turned out that GIS learning was particularly helpful for specific spatial tasks such as finding the best location for an activity when given diverse spatial information (item #2), identifying spatial correlations between sets of maps (item #5), and identifying spatial data types such as point, line and polygon (item #7) (See Table 9). The findings of this study almost coincided with the prediction of the GIS instructor, who expected improvements by GIS students on items item #1 (map overlay operation), item #2, and #7. Assuming that students already had enough cartographic/map-reading skills, the instructor did not emphasize these skills in class, and thus did not predict improvements on items such as orienting to real world frame of reference (item #3) and imagining maps from verbal description (item #4). It is interesting to note that items #1 (map overlay operation) and #2 (finding the best location) were believed to measure the same trait as "overlaying and dissolving maps" but led to different results. GIS students outperformed their control group counterparts on item #2, but not on item #1. This outcome may have been caused by similarity between item #2 and examples of spatial analysis which GIS students worked out during their lab exercises. Since students dealt with similar examples during their labs, they might have felt more comfortable when confronting item #2 than item #1. This hypothesis was supported by anecdotal discussions with some of the test takers. This finding supported previous research by Albert and Golledge (1999) who found no significant differences in performance between GIS-users and non-users for similar types of map overlay operations.

The better performance by GIS students on item #5 (identifying spatial correlations) indicated that GIS learning positively affected students' abilities to "recognize spatial distributions and spatial patterns," and to "compare, associate, and correlate spatially distributed phenomena." This finding conflicts with research by Baker (2002), who did not find improvements of this type.

Cartography students also performed better than the control group on item #5 (identifying spatial correlations). In Computer Cartography, students were exposed to a variety of spatial data and maps during both lectures and labs. Consequently, they may have increased their spatial ability to find spatial patterns and relations. However, significant differences between the cartography group and the control group were not found for items #3 (orientating to real world frame of reference) and #4 (imagining maps from verbal description); these items were also believed to require students to use their cartographic/map-reading skills. Actually for item #3, cartography students raised their scores (the rate of correct answers was 19.5 percent and 33.3 percent for pre- and posttest respectively), but this increase was not statistically significant when compared to the control group (who scored 31.1 percent and 37.1 percent respectively). In regard to item #4, and taking into consideration the rates of 86 percent and 72 percent correct answers by cartography students in the pre- and posttest, it can be assumed that cartography students already had enough of the cartographic/map-reading skills required for this item.

The better performance by the GIS group on item #7 (identifying spatial data type) indicated that GIS learning could advance students' spatial cognitive abilities to "imagine maps from a verbal description," and to "recognize spatial patterns." The GIS students who clarified concepts for spatial data may have become proficient in identifying structures of spatial information.

This study verified that GIS learning positively affected the spatial ability of students. This finding supports previous research asserting strong correlations between GIS-based learning and spatial thinking (Hall-Wallace and McAuliffe 2002), and between learning with GIS and spatial-visual thinking skills (Hagevik 2003).

Research Question 1b

Will these effects be different for male and for female students? Will these effects differ by students' academic majors? The second research question asked if students of different gender or fields of study benefited differently from completion of a GIS course. Very few differences in spatial skills improvement were found when comparing students of different gender or different major.

With regard to gender, male students performed better than females on pre- and posttests ($p = .018$ and $p = .019$ respectively). However, ANCOVA did not find significant gender-related differences in students' score improvements ($p = .571$). It should be noted that, although differences in the pre- and posttest were statistically significant, there was a mixed pattern in the performance of the two groups with some female students performing well and some male students performing poorly on the spatial skills test. These results are in agreement with findings by Hagevik (2003) and

Allen (1974) who reported higher scores for males on the spatial reasoning tests. Other studies (e.g., Vincent 2004), however, found little or no difference in the spatial ability of males and females.

In general, males outperform females in spatial visualization ability (Chadwick 1978; Harris 1978; Kali and Orion 1996; Liben 1981; Maccoby and Jacklin 1974; McGee 1979a; Sherman 1980). Connor et al. (1977) and Goldstein and Chance (1965) argued that males tend to get marks closer to the maximum score than females on pretest, and since females are farther from the maximum score, they potentially have larger room for improvement after training. For example, Saccuzzo et al. (1996) reported that men outperformed women in the pretest, but that women showed a much higher rate of improvement after training.

This study found that male students, even though having scored higher than females on the pretest, still improved their spatial ability as much as female students (Table 11). Both males and females increased their spatial ability significantly after the GIS learning experience ($p = .001$ and $p = .034$ respectively). Therefore this study can argue that both males and females have substantial room for improvement in spatial ability through training.

Irregular patterns of improvement were identified within female students: some of them improved substantially while others remained at the same level or even scored lower. These differences among females may be related to their computer skills or attitudes toward computer usage. However, tests evaluating the participants' computer skills or attitudes were not conducted during the experiment, and in the context of this research this issue remains unresolved.

Participants' performance on the spatial skills test was also analyzed according to their different academic majors. A paired sample *t-test* followed by ANCOVA showed that both the geography majors and the science and engineering majors improved their spatial ability after the completion of a GIS course, and that there were no significant differences in the rate of improvement of the two groups. This finding agrees with previous research, in which no relationship between fields of study and spatial cognitive test scores in the context of GIS were found (e.g., Hagevik 2003; Vincent 2004).

When analyzing the distribution of scores of geography and science and engineering students, it was found that the former showed smaller standard deviations than the latter. This difference may be attributed to the more varied background that science and engineering students were previously exposed to, given that this group of students was composed of individuals majoring in a variety of disciplines. If spatial abilities are important in the use of GIS (Montello et al. 1999), this finding suggests that GIS educators should be aware of the wider variation in spatial ability of non-geography students.

Research Question 1c

Is there a relationship between students' spatial abilities and learning achievement in a GIS course? The third research question dealt with the relationship between the participants' spatial ability and their scores in the GIS course. Students' performance on the spatial skills test was correlated with their lab exercises scores, mid-term score, and final exam score. The impact of the type of final assignment (paper vs. project) on the spatial skills test was also examined. It was hypothesized that (1) positive correlations between students' spatial abilities and their performance in a GIS course would exist; (2) the posttest of spatial ability would have a stronger correlation with lab exercises than class exams because lab exercises demand more intensive hands-on spatial cognitive processes; and (3) the participants who chose a project instead of a paper as their final assignment would have a greater increase in their spatial ability than their counterparts.

The results of this study can be compared to some previous research. For example, Hall-Wallace and McAuliffe (2002) found positive correlations between students' spatial ability and performance in a posttest that covered material similar to what was learned during a set of GIS-related activities. Orion et al. (1997) also found significant correlations between overall geology class scores and spatial skills tests. Conversely, research by Vincent (2004) found very little relationship between students' spatial ability scores and their lab and exam scores in a GIS course.

The first hypothesis that this study advanced is only partially supported by empirical evidence. Relatively strong correlations exist between the two spatial skills tests and the final exam [.443 (p = .027) and .329 (p = .108)] and between the two spatial skills tests and the lab exercises [.357 (p = .080) and .405 (p = .044)]. However, correlation with the mid term is weak [.185 (p = .377) and .213 (p = .307)]. It is noticeable that correlations between the spatial skills test and the lab exercises became stronger after GIS learning experience. These findings indicate that the participants improved their spatial ability during the experimental semester.

The second hypothesis is supported by the results of correlation analyses. Posttest spatial ability has a stronger correlation with lab exercises than class exams. Considering that the lab exercises were relatively simple (i.e., demanding few spatial cognitive processes) it is possible that the correlation could have been higher than 0.044. The simplicity of some of the problems faced by students in the labs was mentioned by several study participants.

> The labs from the textbook we used were very basic. They were a good introduction. They were very easy and very basic. … Well, the labs talk you through, and, it's not just what theoretically you're trying to do, but it'll tell you everything from what to click on, to what file you're looking for.
>
> You get instructions for lab. You just go bang, bang, bang, and do them. And turn it in, you know, do the minimal amount possible and then, you know, when comes time to do it, and put it all together, you've forgotten… Or maybe never really learned it and just followed the steps.
>
> It [doing labs] was just more, just getting familiar with software instead of actually having to use it. However, the difference was not stronger than assumed.

It is also interesting to note the strong correlation between the final exam and the pretest of spatial ability which was administered before the actual treatment. Since the final exam required fewer of the spatial abilities acquired during the GIS experiences than lab exercises, exam scores should be more directly correlated to the students' intellectual potential already reflected in the pretest.

Regarding the final assignment, because paper assignments focus more on GIS theoretical content than on the analytical or visual aspects of GIS, those students who completed a GIS project were expected to show greater increases in spatial ability than students who completed a paper. ANCOVA, however, revealed that there is no significant difference in score improvement between the paper and project groups ($p = .778$).

Even though an analysis based on quantitative data did not show significant differences, qualitative data obtained from student interviews provided some additional useful information. This is particularly significant for the types of projects assigned to students, the types of experiences students gained from a project, the relationships between labs and projects, and how project assignments could be enhanced.

> Lab is just you know do this, click this. It…this [project] is more like real world situations. You know, I was pretending I was with a business, and I had to figure out where to put a new pizza store location. That's what I did for mine [project].
>
> Working on the project made me do that [combining multiple labs], so, and that's what helped.
>
> I've learned more during the project than I learned what to do during class. Because this is actually…you know, like … analyzing.
>
> I thought it would be a good opportunity to fully assess what I had gained in 390 [Introduction to GIS class] in order for me to assess if I should go on to 475 [advanced GIS class]. And uh, I think I did just that. I felt that doing a report would just, would be more of a…something I could just research. As far as the project goes, I would have to use stuff that I learned in lab as well as stuff I learned in research, and bring them all together.

Educational Implications: GIS Lab Exercise, Project, and Their Relationship

Usually an individual lab exercise is developed to cover a single topical procedure such as changing map projection, georeferencing, network analysis, etc. Completing a lab exercise implies that students will (1) recognize the same or similar problems (or procedures) when they encounter real-world situations later, and (2) apply the specific procedure or application they learned from the lab appropriately to the problem. In reality, however, the lab exercises are often overly simplified whereas real world projects are so complicated that students cannot recognize the problem and apply the proper procedure or application (Forer and Unwin 1999).

The development of lab exercises typically follows a kind of "divide-and-conquer" approach that divides real-world problems into smaller sub-problems, each of which is covered by a single lab exercise. In addition, lab exercise development depends on the principles of "transfer" assuming that knowledge or skills from lab exercises can be transferred to real-world projects. The divide-and-conquer approach is often applied in artificial intelligence to solve large problems efficiently. The solution of the entire problem is obtained by solving smaller sub-problems. The procedures that solve mini-problems are combined to get larger applications, and then these are combined again to get even larger procedures (Kammár et al. 1998). However, the divide-and-conquer approach cannot guarantee the transition from solving a collection of simple sub-problems to a solution to a complicated larger problem. Bednarz (1997, 2001) points out the same problem:

> Students knew how to do it (one can assume that from the fact that they completed the course with an above average grade), but they could not state what it was they could do. … The step-by-step instructions offered in the lab served as "training wheels" but it was not until the wheels were removed and students had to pedal off by themselves that real learning took place.

The use of learned outcomes to facilitate learning in other situations is generally referred to as transfer of learning. When students (1) are taught in multiple contexts or from multiple examples, (2) are guided to use multiple skills (labs) rather than a single lab procedure for their projects, and (3) work with actual local data, they will be more able to transfer knowledge and skills successfully from labs to projects and from projects to real-world situations (Anderson et al. 1996; Bransford et al. 2000; Brown and Kane 1988; Gick and Holyoak 1983; Lodico et al. 1983; McCombs 1996; Nixon and Kanak 1981; Reed and Bolstad 1991; Sweller and Cooper 1985).

Research has indicated that transfers across contexts are especially difficult when a subject is taught in only a single context rather than in multiple contexts (Anderson et al. 1996; Nixon and Kanak 1981). Transfer of learning is enhanced when learning involves multiple examples rather than a single example (Reed and Bolstad 1991; Sprio et al. 1992; Sweller and Cooper 1985). These findings provide useful guidelines to the development of GIS lab exercises that would allow GIS learners to develop usable and conditionalized knowledge supporting transfer of learning. For instance, students can be asked to elaborate on the multiple aspects of one problem, then be provided with similar problems and asked for slightly different solutions, and then finally be required to deduce to what degree their learning may be applicable to the real-world.

There are few real-world problems that one can solve with a single GIS procedure. If students are guided to use multiple labs (skills) in their projects, they will be more likely to develop skills applicable to real world problems, which often require combined on multiple knowledge and techniques.

Learners are often motivated by working with local data that they are familiar with because they can easily perceive the potential application of what they are doing in class to their community or workplace. Anecdotal interviews with GIS students support this argument:

> If you can show something for most people, I think, well, at least especially with me I find that if you put something into a… related to real world situation, it's a lot more easily understood.
>
> [If we can work with local data users are familiar]… It's more interesting to work with because you're more familiar with town.
>
> You spend more time on it [project] than just…it becomes more familiar.

Research Question 2a

Will completion of a GIS course affect the map-drawing strategy of college students? This research question examined if GIS learning helped students change the strategy they used in spatial tasks. People's spatial problem-solving strategy was measured by analyzing their map-drawing strategy in a cognitive-mapping test. The research presumed that the individuals' map-drawing strategies would reveal information about the cognitive processes people use in spatial environments. Based on video tape segments of participants constructing their sketch maps, strategies were classified as hierarchical, regional, or mixed. Map-drawing strategies were considered as "hierarchical" when subjects started by drawing the main roads across the entire map. Strategies were considered as "regional" when subjects completed their maps by working in one sub-area at a time, only moving to a new sub-area after completing the previous one. Some students used a strategy based on a combination of both hierarchical and regional strategies; this strategy was called "mixed."

According to Chase and Chi (1979), some subjects, usually the most sophisticated, tend to work in a top-down fashion; others, less sophisticated, move bottom-up. The greater the number of hierarchy levels, or the more systematically constructed, the greater the chances of being accurate (Beach and Mitchell 1978). One the one hand, since a hierarchical strategy tackles spatial problems systematically and hierarchically (i.e., from a larger to a smaller area or from the whole to a detail), this approach has the possibility of being more accurate and thus can be considered as top-down and the most sophisticated strategy. On the other hand, since a regional strategy solves spatial problems based on spatial proximity of the elements in the task (i.e., line-by-line), this approach can be considered as bottom-up and least sophisticated.

Since GIS can be considered as a tool for spatial problem solving, it was assumed that GIS learning would help learners improve their spatial problem solving. This study assumed that GIS learning would encourage students to change their map-drawing strategies from regional to mixed or hierarchical, from mixed to hierarchical, or from hierarchical 2 to hierarchical 1. This hypothesis is partially supported by empirical findings. However, as more than half of the participants used either H1 or H2 in drawing their first maps, there was an intrinsic limitation (small sample size) in verifying this research hypothesis. Out of 46 students that completed either Computer Cartography or Introduction to GIS, 41 percent of the students (19 of 46) changed map-drawing strategies from their first map to their second map. In 10 out of 13 cases, the changes observed in the group of students taking GIS support the research hypothesis; five students changed their map-drawing strategies from H2 to H1, three students changed from the mixed to H2, one student changed from the regional to H1, and another student from the regional to the mixed. These findings are consistent with other research also reporting that strategy use in spatial skills tests can be changed by training (e.g., Glück et al. 2002). In regard to students who took only the cartography course, however, only three out of six (a half of the cases) agreed with the research hypothesis.

Students' experience with the cognitive-mapping pretest may also have affected the participants' performance on their second maps. Psychological research shows that people are able to change their level of planning in response to characteristics of the environment and improve their problem-solving performance (O'Hara and Payne 1998; Gunzelmann and Anderson 2003; Kirsh and Maglio 1994). For example, Gunzelmann and Anderson (2003) found that their subjects increased the level of planning in a spatial task as they became more familiar with the task. Thus, some of the changes observed in the GIS group may be the result of the practice effect of the pretest.

Research Question 2b

Is there a relation between students' map-drawing strategies and spatial ability? This study intended to verify the level of correlation between students' map-drawing strategies and their spatial ability. It was assumed that students who employed the most sophisticated strategy would score higher on the spatial skills test than students who used less sophisticated strategies. The results, however, do not support this hypothesis. Participants using hierarchical strategies (assumed as more sophisticated) did not score higher than students who used either the mixed or regional strategies. Actually, students who used the regional strategy scored highest on the spatial skills test although the difference was not significant (p = .284).

In order to understand the relatively better performance by users of regional strategies in the spatial skills test, it is helpful to examine the four different map-drawing strategies in terms of a planning continuum. Even though there are differences in drawing styles, both regional strategy (mapping one sub-area at a time before moving into another) and the H1 strategy (mapping almost all of the roads before placing any target sites) might have more similarities between them than the H2 and mixed strategies, since participants who used them attempted to envision the entire map from the beginning. The longer drawing time required by users of the regional strategy explains some cost-benefit (time vs. planning) tradeoffs. On other hand, users of the H2 strategy (completing main roads first and then drawing a few secondary roads in order to locate a target) may be constructing a partial plan by drawing main roads first, and then executing actions based on these partial plans, planning as they act. This interactive plan-and-act structure allows for more reactive and opportunistic planning (Anderson 1991; O'Hara and Payne 1998). In summary, users of the regional and H2 strategies could manipulate more information simultaneously than the users of the H1 and mixed strategies, and thus are believed to have a better working memory than their counterparts. This may also result in higher scores in the spatial skills test.

Literature on the expert-novice differences in problem solving provides another possible explanation for the regional strategy. According to Larkin (1981) and Anderson (1980), novices tend to work forward from a problem, line-by-line until they arrive to a solution. Experts, on the other hand, tend to work backward, decomposing each problem into manageable chunks. Thus, sub-areas as drawing units in the regional strategy might be understood as “manageable chunks” in expert problem-solving.

The findings of this study shed new light on a relatively untouched issue–the relationship between spatial aptitude and spatial strategy choice (Bruin et al. 2000). The relevance of spatial strategy to spatial performance has been discussed by a number of authors (Kyllonen et al. 1984a, Lohman and Kyllonen 1983) and others have demonstrated that different subjects can employ different strategies when solving the same spatial task (Allen 1974; Cooper 1980; Freedman and Rovegno 1981; Kyllonen et al. 1984b; Lohman and Kyllonen 1983; Snow 1978; 1980; Schultz 1991). A few authors argued that strategy choice and performance are both related to spatial aptitude (Freedman and Rovegno 1981; Kyllonen et al. 1984a, 1984b). However, little research has been conducted on the relationship between spatial aptitude and map-drawing strategies. Moreover, since psychometric tests have been used to measure the subjects’ spatial ability in the previous studies, comparisons between their findings and those of this study should be attempted with great caution.

On the one hand, this study was able to identify the strategies used in cognitive mapping, to develop a method for assessing these strategies (i.e., video analysis of map-drawing strategies), and to demonstrate a relationship between strategy choice and spatial performance in some instances. On the other hand, this study was not able to address sufficiently the way these strategies can change as a result of training. Nevertheless, the method used in this study can be replicated and applied to new contexts by using multiple spatial tasks having different difficulty levels and by testing different populations at varying scales. This research will enable geographers to gauge the nature and influence of spatial aptitude upon strategy choice.

Summary and Conclusions

Recent educational research supports the assumption that GIS learning can help students develop their spatial abilities and solve spatial problems (Albert and Golledge 1999; Audet and Abegg 1996; Audet et al. 1993; Audet and Paris 1997; Baker 2000; Barstow 1994; Keriski 2000; Salinger 1995; Self et al. 1992; Wigglesworth 2000). Empirical research, however, has been insufficient to understand to what extent GIS learning can accomplish those goals (Hall-Wallace and McAuliffe 2002; Kerski 2000).

The major objective of this study was to examine the effect of GIS learning on the spatial ability and spatial problem solving of college students. Since GIS is a tool for spatial analysis, spatial visualization, and spatial problem solving, this study hypothesized a relationship between GIS learning and spatial ability (or spatial problem solving). The two major research questions that this study aimed to answer were the following:

1. Will GIS learning improve students' spatial ability?
2. Will GIS learning improve students' spatial problem solving?

The first research question examined the effect of GIS learning on spatial ability. Changes in students' spatial ability were measured by a spatial skills test created specifically for this study. The spatial skills test contained multiple-choice questions and performance exercises to evaluate the students' spatial ability, including overlaying and dissolving a map, reading a topographic map, finding the best location based on given spatial factors, correlating spatially distributed phenomena, constructing contours based on point data, and recognizing different types of spatial data.

The spatial skills test was quasi-experimental and used a non-equivalent pretest-posttest control group design with four groups. These four groups included a control group (N=35), a GIS group (N=18) of students who had completed the Introduction to GIS course, a cartography group (N=17) of students who had completed the Computer Cartography course, and a group (N=10) of students who had completed both courses sequentially or concurrently. All these courses were offered by the department of geography of Texas A&M University in the 2003 fall semester. All the participants in the four groups completed a pretest and posttest administered at the beginning and end of the same semester.

The second research question examined how GIS learning affected spatial problem solving. Changes in the students' spatial problem solving were measured by a cognitive-mapping test also created for this study. This study assumed that the analysis of the individual map-drawing strategies would reveal information about the cognitive processes participants used to solve their spatial tasks. The study used a qualitative methodology to identify the strategy that students applied to complete their cognitive-mapping tests; this methodology was based on the observation (and videotaping) of participants while they completed their tests, complemented by information from interview questions related to the way they were trying to complete the task. The cognitive-mapping test required participants to draw a sketch map of a familiar region; this process was videotaped in order to identify and classify each subject's map-drawing strategy. A total of 64 participants, recruited among students enrolled in Introduction to GIS and Computer Cartography at Texas A&M University, completed this exercises. Both pre- and posttests were administered during the 2003 fall semester.

The six major findings of this study are summarized in the following paragraphs.

First, this study used an innovative methodology to evaluate the influence of GIS in the development of spatial skills. This was the first attempt to build a paper-and-pencil test that could directly measure components of spatial relations skills. Virtually no research has been undertaken on spatial relations in the area of spatial cognition, either by geographers or psychologists.

Second, this study demonstrated that, in an experimental setting, GIS learning helps students improve their spatial ability. More specifically, completion of a GIS course helped students in (1) finding the best location under a specified set of spatial conditions, (2) identifying spatial correlations between sets of maps, and (3) identifying spatial data types (e.g., point, line, or polygon). Strong correlations existed between the participants' spatial ability and their performance in the GIS course. The study also found that the spatial ability improvement linked to GIS learning was not significantly related to differences in gender or to academic major (geography majors vs. science and engineering majors).

Third, this study identified two distinctive map-drawing strategies: hierarchical and regional. Strategies were classified as hierarchical when subjects began by drawing the main road network across the entire map, and as regional when they completed mapping sub-areas before moving on to another sub-area. The results of this study suggested that users of both hierarchical and regional strategies had similar knowledge about, and understanding of, their environment. Users of the hierarchical strategy, however, seemed to convey their knowledge more efficiently. In addition, this research found the anchor hypothesis and rational analysis framework were helpful concepts in analyzing people's map-drawing strategy.

Fourth, the study demonstrated that the analysis of map-drawing processes based on videotaped data was a viable way to analyze individuals' spatial problem-solving strategy. Videotaped records of students taking part in this study were categorized easily and accurately into two major types (hierarchical and regional), enabling further hypotheses about the students' cognitive skills and knowledge to be explored with confidence.

Fifth, after completion of a GIS course, a significant number of participants (about half, or 19 out of 46) changed their map-drawing strategies. Detailed descriptive facts about strategy changes were provided in both quantitative and qualitative form. However, more research is necessary to address why these changes in strategy come about.

Finally, this study shed light on the relatively untouched issue of the relationship between spatial aptitude and spatial strategy selection. Users of the regional strategy performed better on spatial skills test than users of other strategies although the difference was not statistically significant. Neither participants' gender nor academic major affected their choice of mapping strategy.

Suggestions for Future Research

In this study several innovative research methods were utilized to investigate the relationships between GIS learning experiences and spatial abilities. This initial research could be improved in future studies in three major areas.

First, numerous studies concerning spatial abilities have been conducted but the spatial relations factor has received insufficient attention. Golledge (1993) argued that virtually no research had been undertaken on spatial relations within the area of spatial cognition, either by geographers or psychologists. This study made an initial attempt to develop a paper-pencil test that could directly measure selected components of spatial relations, but new and more refined tests should be developed. In order to reinforce the validity and reliability of these tests additional empirical research should be performed involving the measurement of spatial relations, especially the significance of the scale factor. Several researchers have used table-top and paper-and-pencil tests to infer spatial ability at a larger geographic scale (Kitchin and Blade 2002), but it is still unclear to what extent spatial ability measured by small-scale and paper-and-pencil tests may be different from spatial ability measured by large-scale and authentic performance tests (Allen 1999).

Second, this study developed a method for assessing the choice of a spatial strategy by subjects asked to draw a cognitive mapping (i.e., video recording map drawing in order to identify the strategies chosen by participants). Video analysis of map drawing has the potential to identify the ways individuals solve spatial problems. More research addressing the relationships between map-drawing strategies and problem-solving strategies are necessary. There is also a need to better understand the spatial cognitive processes behind the map-drawing strategy of individuals. For example, extending and developing the research of Lawton (1994) who used a questionnaire to assess subjects' level of reliance on route (use of landmarks) versus orientation (self in relation to environmental reference points) strategies of way-finding would be helpful in identifying the rationale behind spatial strategies.

And finally, the relationship between strategy choice and spatial performance demonstrated by some individuals in this study needs further attention. Additional research about the relationship between individuals' spatial ability and their choice of strategy for spatial problem-solving is necessary. Findings in this study must be linked to and discussed in the broader context of other disciplines such as behavioral geography, educational psychology, developmental psychology, and in multidisciplinary frameworks. The methods used in this study should be replicated and applied to new contexts by using multiple spatial tasks of different levels of difficulty and by testing different populations at varying scales.

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APPENDIX 1

Spatial skills test

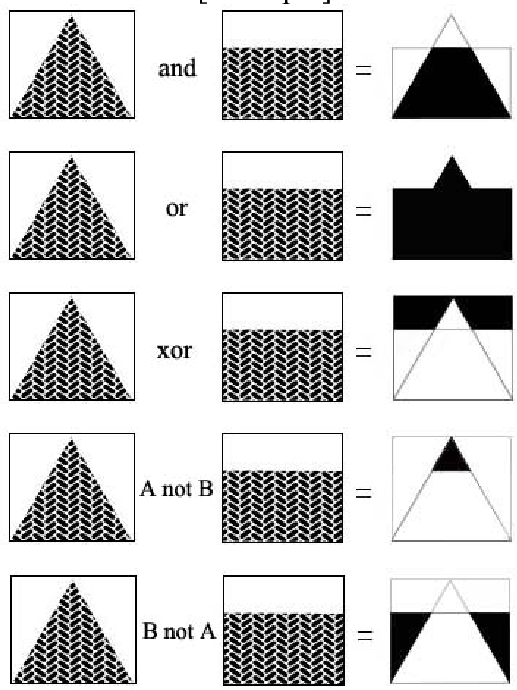
Pre-Test

Personal Information

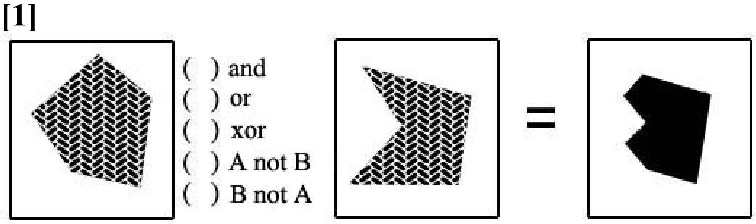
1. Name:
2. Major:
3. ☐ Freshman / ☐ Sophomore / ☐ Junior / ☐ Senior / ☐ Graduate
4. Gender: ☐ M / ☐ F
5. Have you ever taken a GIS course? : ☐ Yes / ☐ No
    a. If you “Yes”, which GIS course?
        ☐ Geog 332 (Thematic Cartography)
        ☐ Geog 361 (Remote Sensing in Geosciences)
        ☐ Geog 390 (Principles of Geographic Information Systems)
        ☐ Geog 475 (Advanced Geographic Information Systems)
        ☐ Others ( )

Direction: Solve the following questions based on the example below. Please mark (√) an answer **[Question 1-2]**

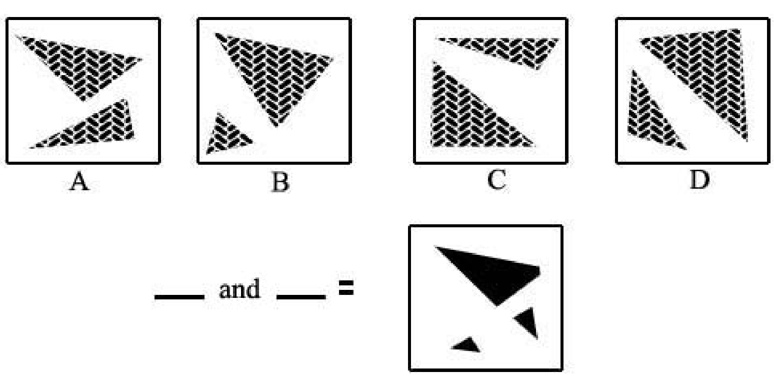
[Example]



[1]

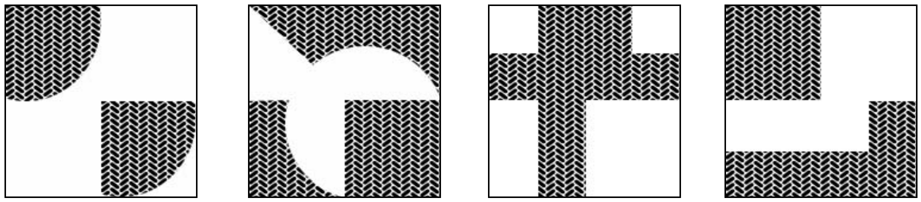


[2]



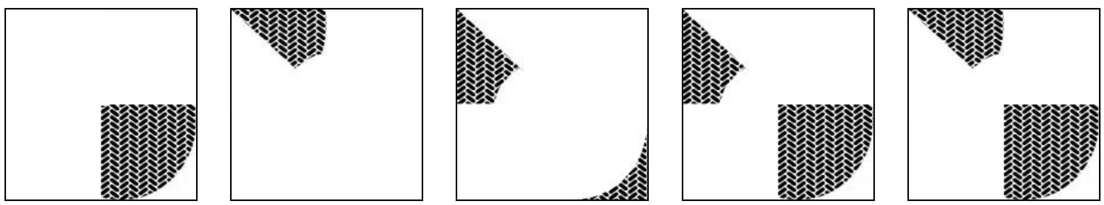
Question 1 and 2 were adapted from Albert and Golledge (1999)

Direction: Based on figures below, solve the following questions. Please mark (√) an answer **[Question 3-4]**



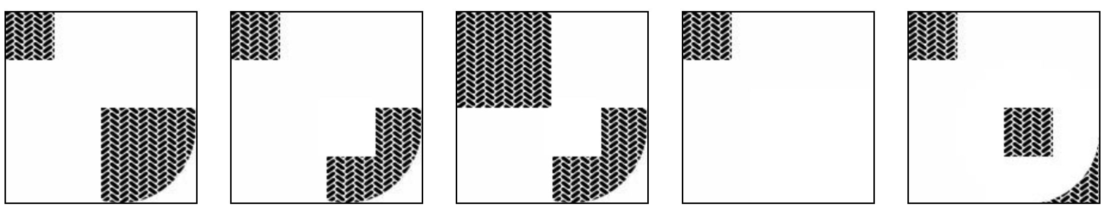
(A) (B) (C) (D)

[3] A and **B** =



( ) ( ) ( ) ( ) ( )

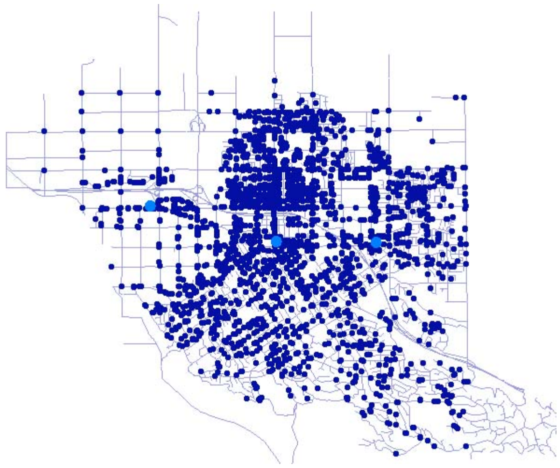
[4] (not **C**) and **A** and **D** =



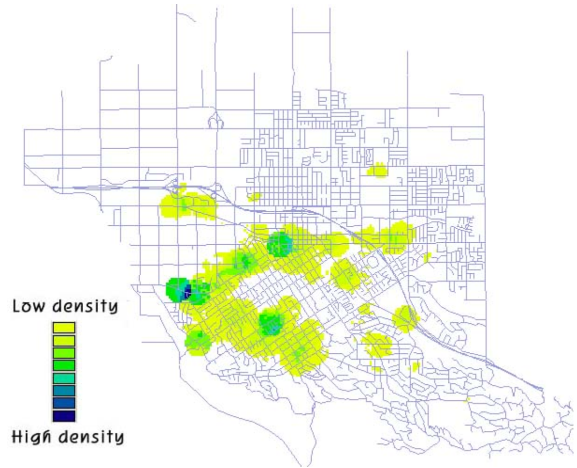
( ) ( ) ( ) ( ) ( )

Direction: Find a new best site for a coffee shop based on the following conditions. **[Question 5]**

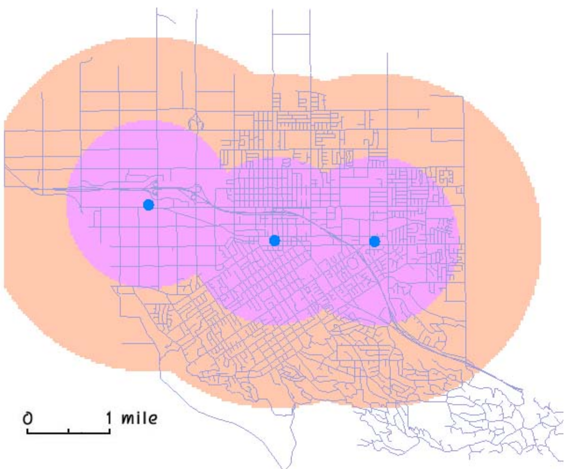
- Possible site for a new store should be more than 1 mile from any existing stores. If any stores are closer than 1 mile, they may compete with each other for customers.
- Possible site for a new store should be easy for potential customers to access. ‘Customer density’ shows the density of coffee drinkers who have visited the three stores over the last year.



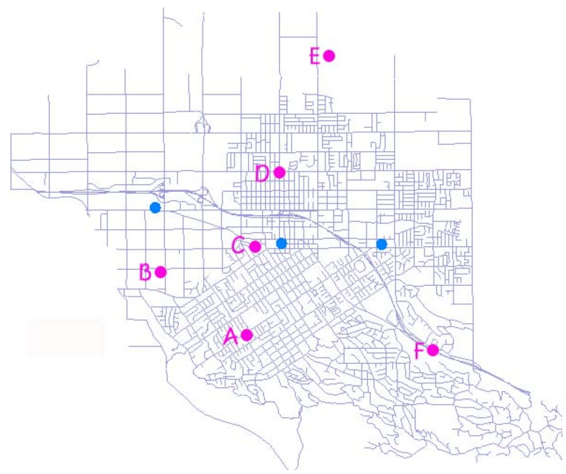
Population distribution



Customer Density

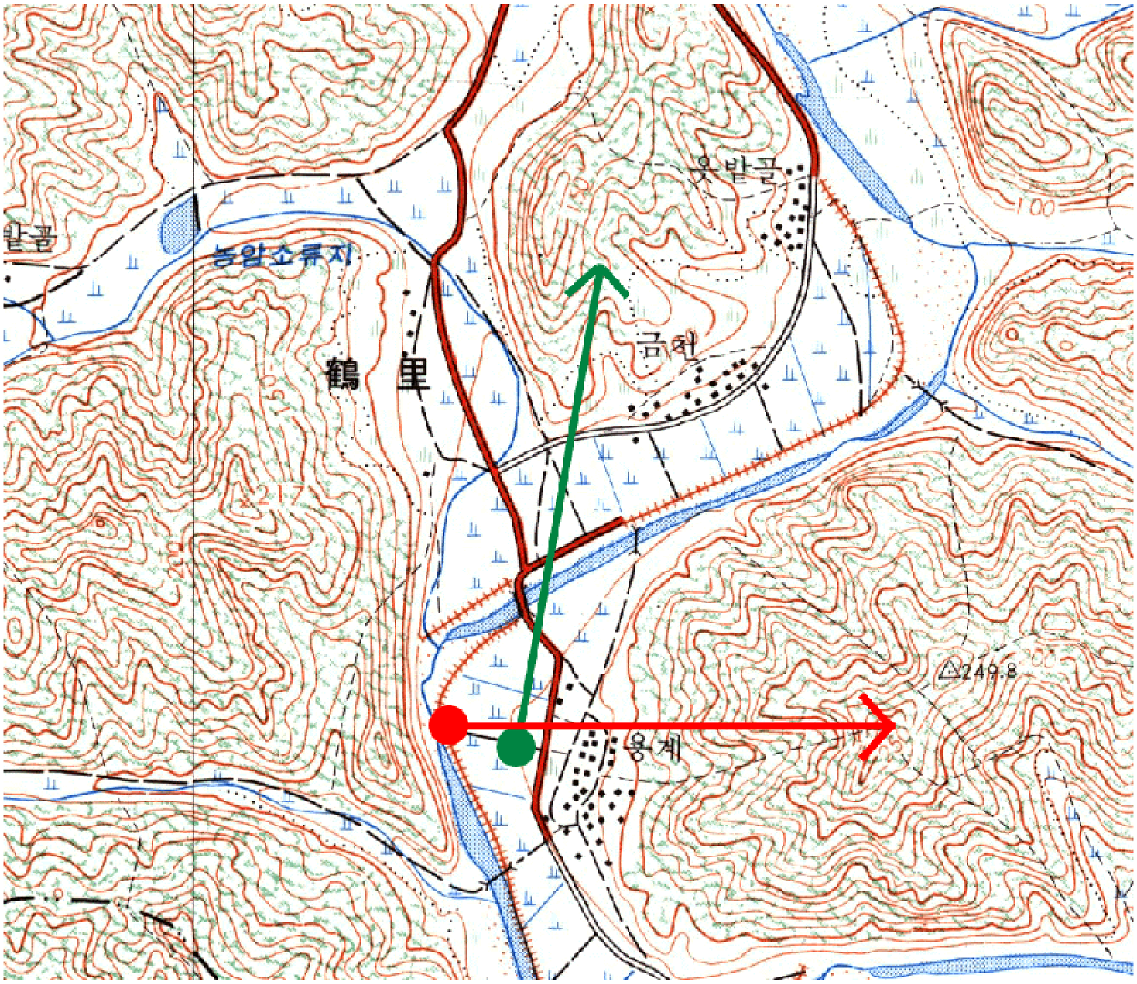


Distance from existing stores



Potential store location

[5] Mark (√) on the best site for a potential coffee shop on the map above.



Direction: Imagine that you are standing and looking in the direction of the red (or green) arrow. Among 6 photos (A~F) on the next page, which photo most closely represents what you would see? Mark (√) on your answer **[Question 6-7]**

	(A)	(B)	(C)	(D)	(E)	(F)
[6] Red Arrow						
[7] Green Arrow						

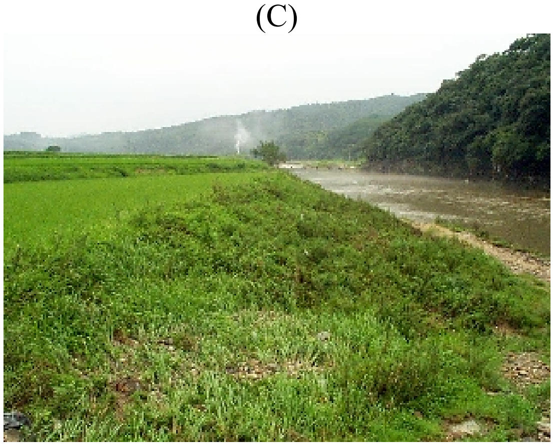
Question 6 and 7 were adapted from personal homepage of J. Ryu (2005)

(A)

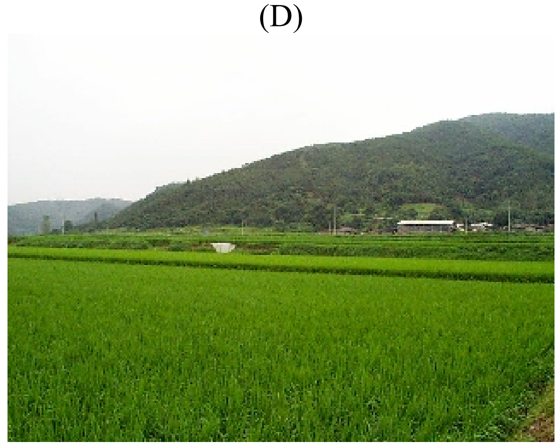
(B)

(C)

(D)

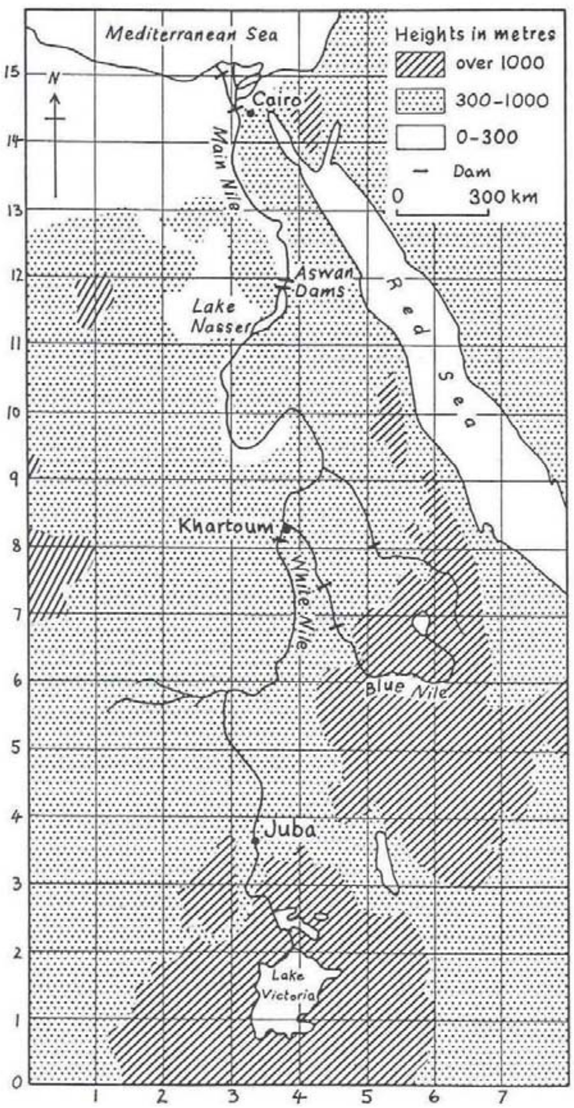


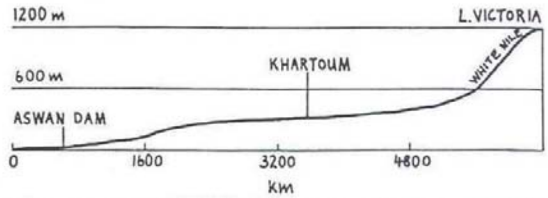
(E)



(F)

Direction: A group of young travelers is making a journey down the White Nile. They make notes as they travel. Below are three pages from their notebook. They are not in order. Based on information below, find the place each note indicates and write grid reference as (X, Y) format. **[Question 8-9]**





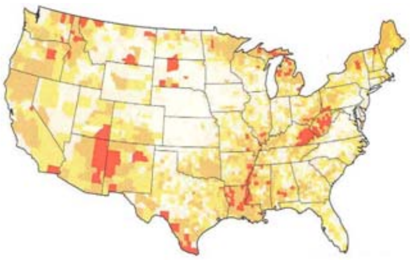
Another river flows into this one. We are close to a large city. The height of the land is about 300 metres. Further upstream there was a dam.
Grid reference: (4 , 9)

The river flows very slowly here. We are approaching a very big delta. A large city lies to the east. Yet another dam lies ahead.
Grid reference: (,)

Here there are two dams close together, down stream of a long, narrow lake. No other rivers have joined this one for many kilometres.
Grid reference: (,)

Direction: Based on maps below, find maps having spatial correlations. **[Question 10]**

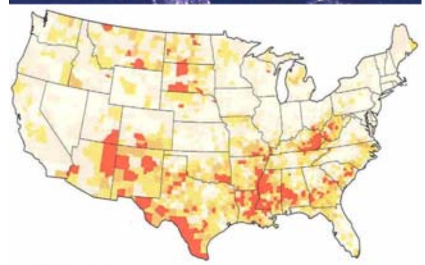
(1)



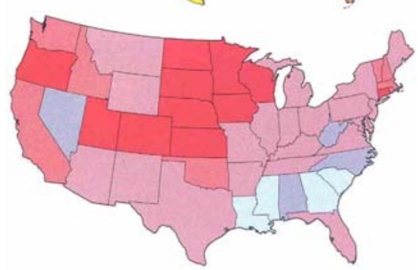
(2)

(3)

(4)

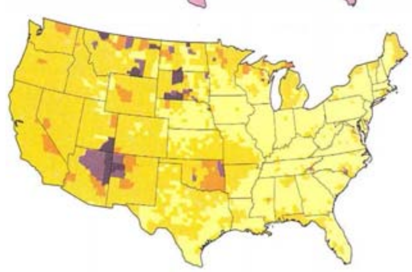


(5)



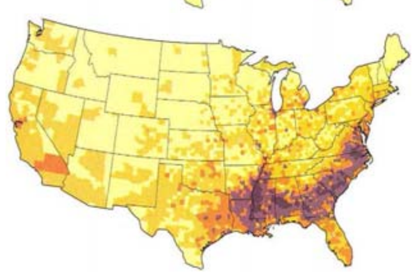
(6)

(7)



(8)

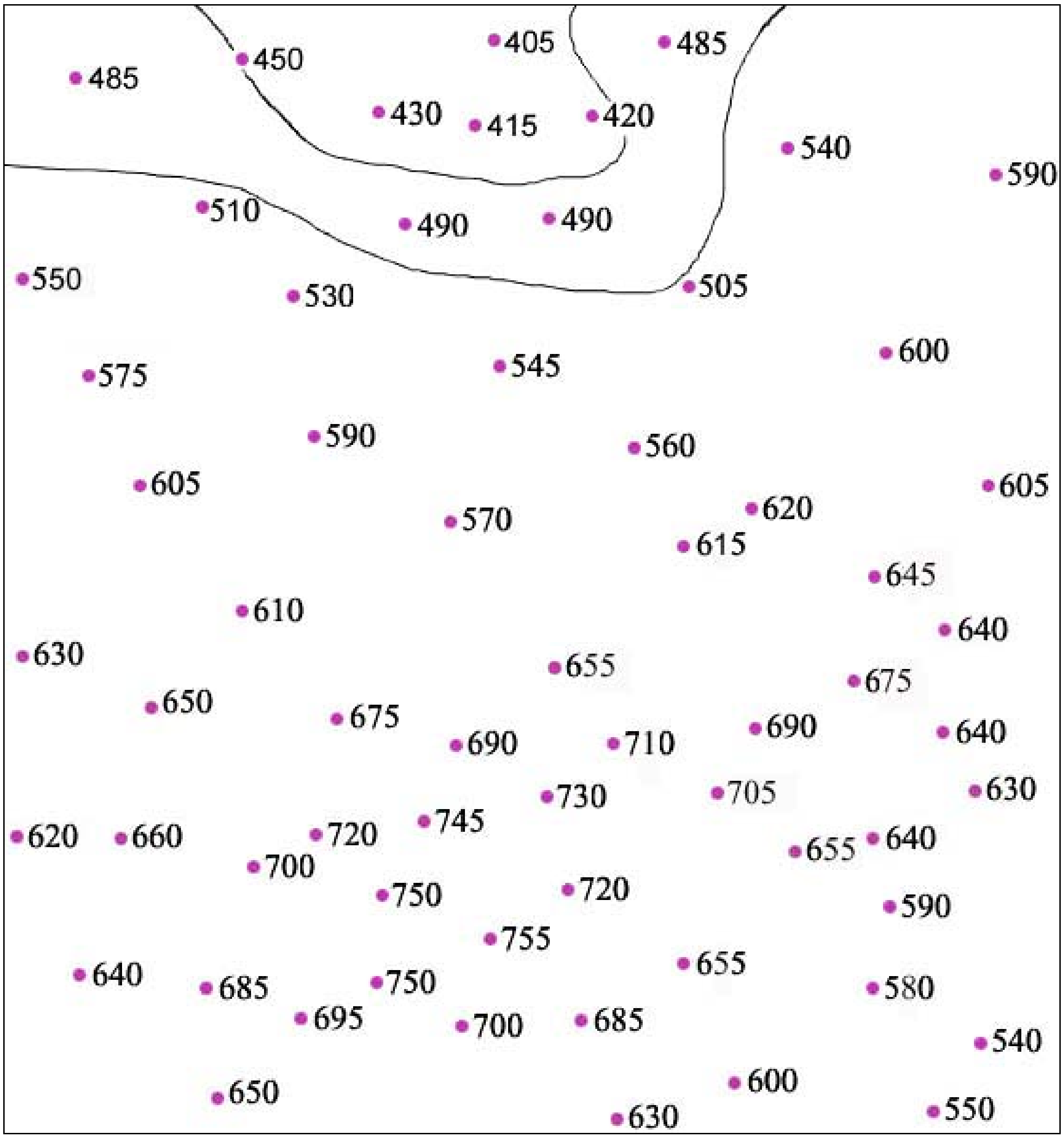
(9)



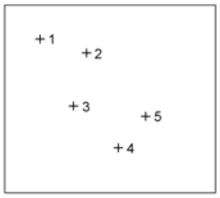
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)									
(2)									
(3)									
(4)									
(5)									
(6)									
(7)									
(8)									
(9)									

[10] Choose best 5 spatial correlations and mark (√) on the un-shaded columns.

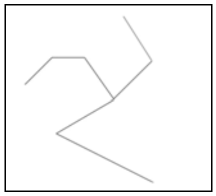
Direction: The values below are indicating elevation of each point. Based on the elevation data, create contour lines. The contour interval should be 50 feet. The lowest contour line is 400 feet. In this way your contour intervals should run 400, 450, 500…
[Question 11]

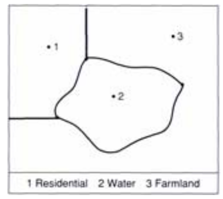


Direction: Spatial information can be displayed based on Point, Line(Arc), Area(Polygon), and Raster(lattice). Based on the sample question below, classify the following spatial data. **[Question 12-17]**



Point


Line (Arc)



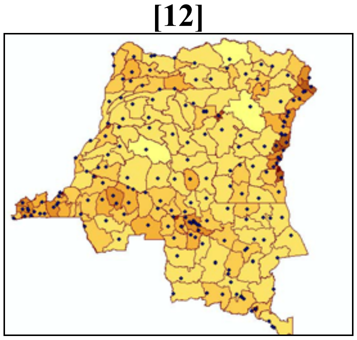
Area (Polygon)

Raster (lattice)

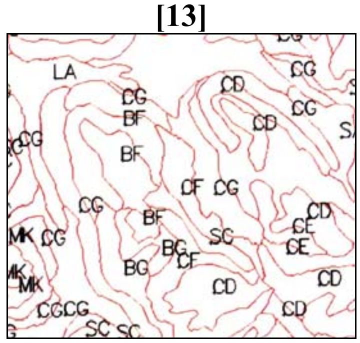
[Sample Question]

[√] Point [√] Line [ ] Area [ ] Raster

[12]

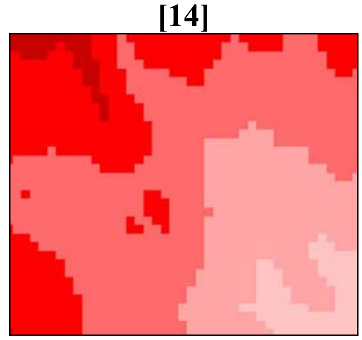


[13]



Soil map

[14]


Elevation

[15] River channels and their basins in Brazos County.
[16] Locations of weather stations in Harris County.
[17] Texas A&M University shuttle bus route in College Station.

Please mark (√) on your answer

	Point	Line	Area	Raster
[12]	[ ]	[ ]	[ ]	[ ]
[13]	[ ]	[ ]	[ ]	[ ]
[14]	[ ]	[ ]	[ ]	[ ]
[15]	[ ]	[ ]	[ ]	[ ]
[16]	[ ]	[ ]	[ ]	[ ]
[17]	[ ]	[ ]	[ ]	[ ]

Spatial skills test

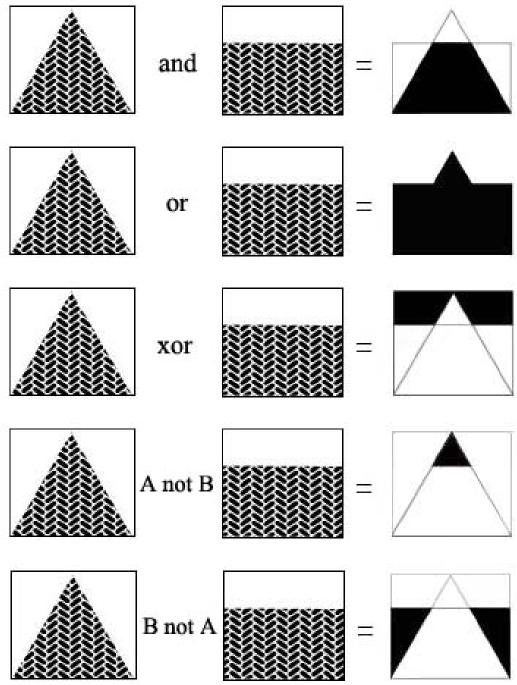
Post-Test

Personal Information

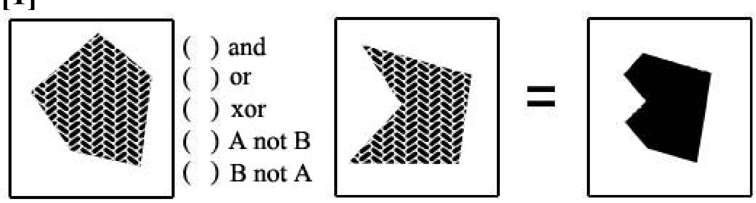
1. Name:
2. Major:
3. ☐ Freshman / ☐ Sophomore / ☐ Junior / ☐ Senior / ☐ Graduate
4. Gender: ☐ M / ☐ F
5. Have you ever taken a GIS course? : ☐ Yes / ☐ No
    a. If you "Yes", which GIS course?
       ☐ Geog 332 (Thematic Cartography)
       ☐ Geog 361 (Remote Sensing in Geosciences)
       ☐ Geog 390 (Principles of Geographic Information Systems)
       ☐ Geog 475 (Advanced Geographic Information Systems)
       ☐ Others ( )

Direction: Solve the following questions based on the example below. Please mark (√) an answer **[Question 1-2]**

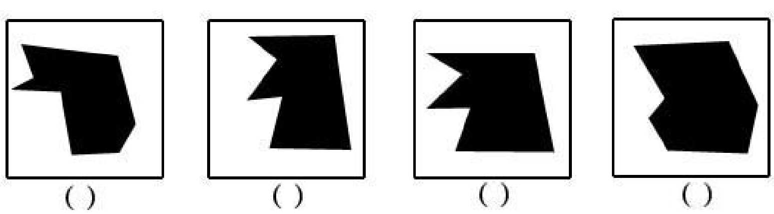
[Example]



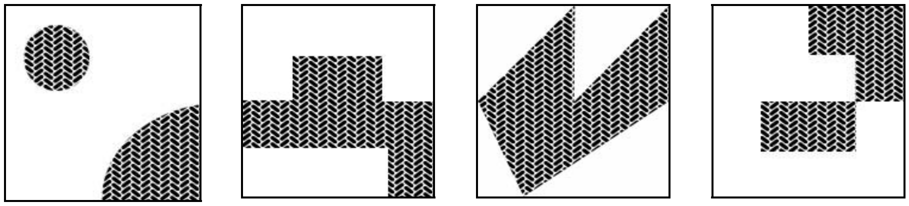
[1]



[2]

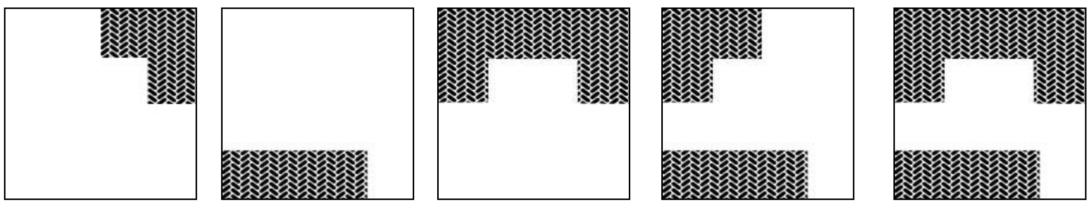


Direction: Based on figures below, solve the following questions. Please mark (√) an answer **[Question 3-4]**



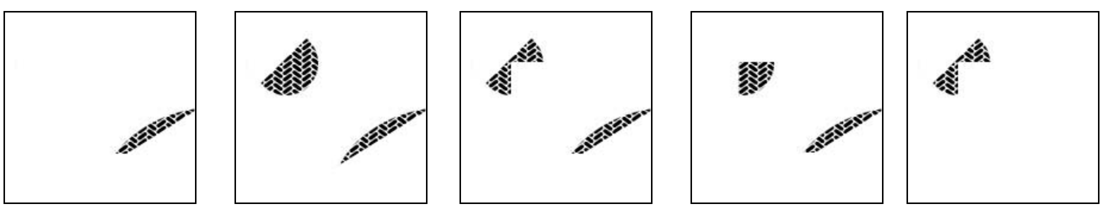
(A) (B) (C) (D)

[3] (not **B**) and **D**



( ) ( ) ( ) ( ) ( )

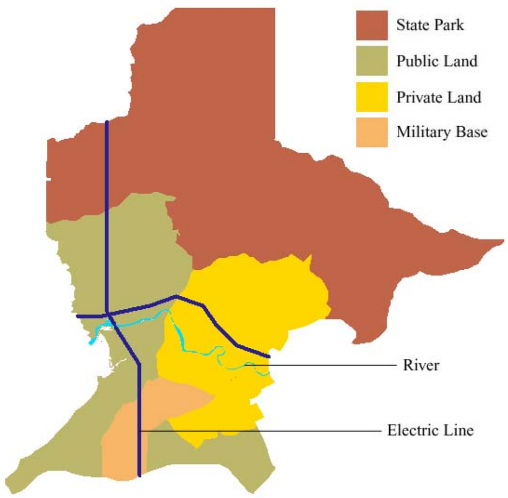
[4] A and **B** and **C**



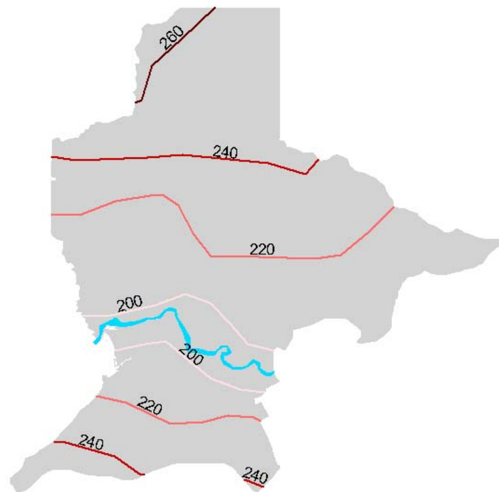
( ) ( ) ( ) ( ) ( )

Direction: Find the best location for a flood management facility based on the following conditions. **[Question 5]**

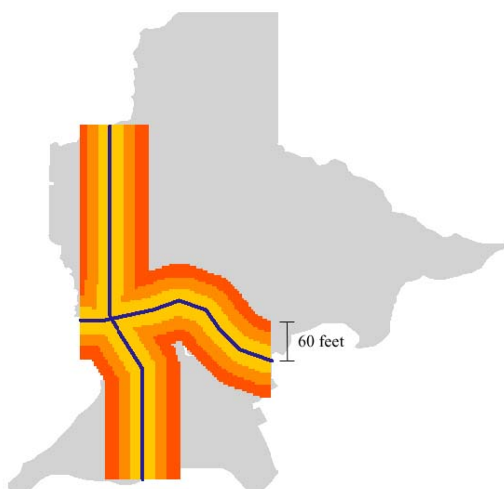
- Possible site for a flood management facility should be within 60 ft of an existing electric line.
- Possible site for a flood management facility should be located less than 220 elevation level.
- Possible site for a flood management facility should be located in State Park or Public Land.



Land use



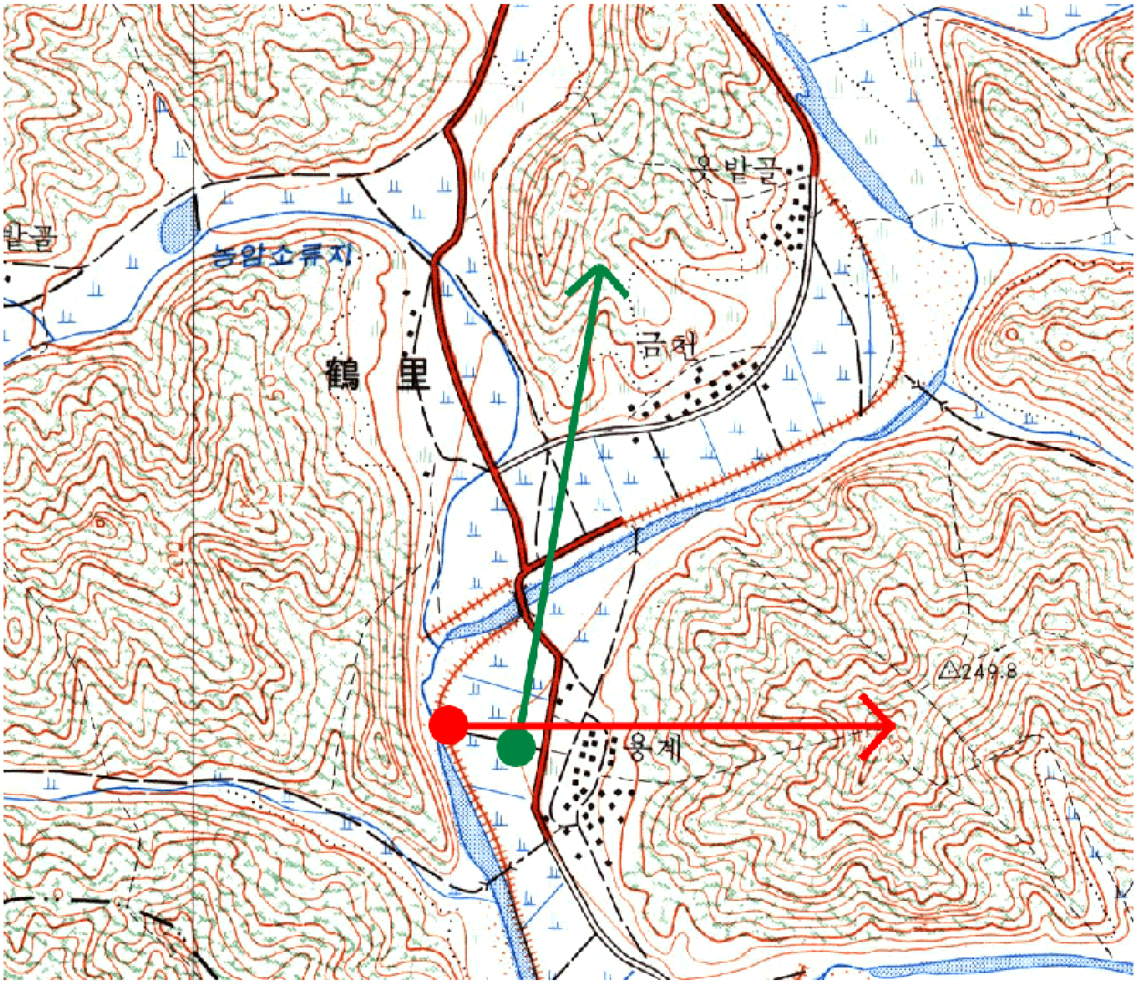
Elevation (feet)



60 feet from electric line

Potential facility location

[5] Mark [√] on the best site for the flood management facility on the map above.



Direction: Imagine that you are standing and looking in the direction of the red (or green) arrow. Among 6 photos (A~F) on the next page, which photo most closely represents what you would see? Mark (√) on your answer **[Question 6-7]**

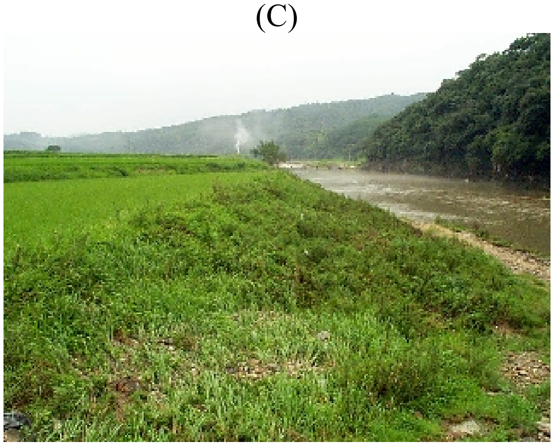
	(A)	(B)	(C)	(D)	(E)	(F)
[6] Red Arrow						
[7] Green Arrow						

(A)

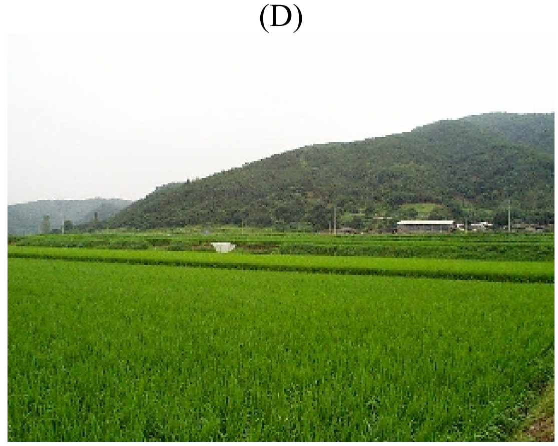
(B)

(C)

(D)

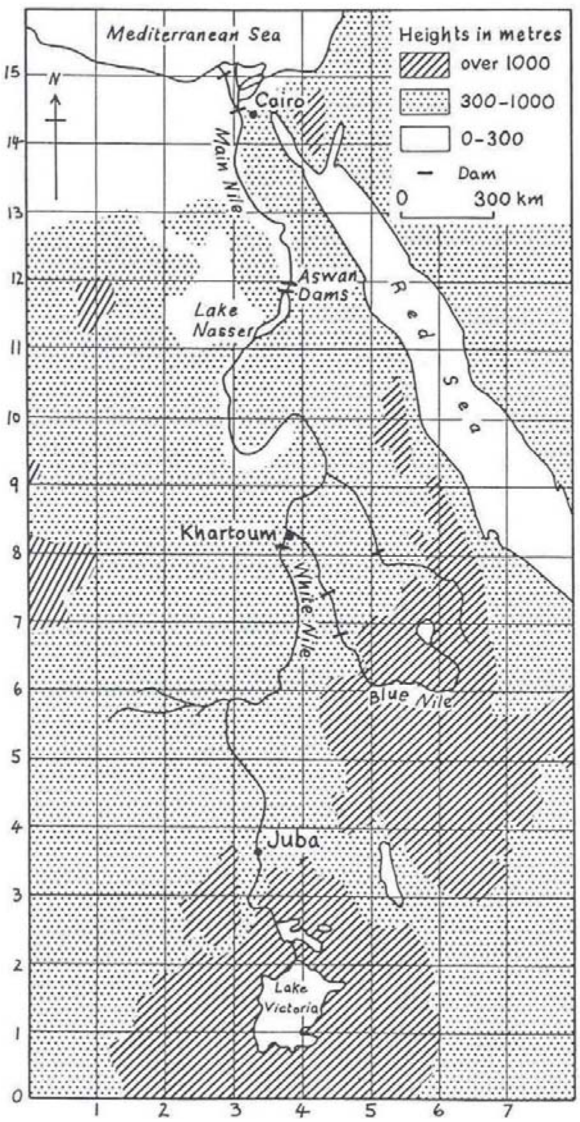


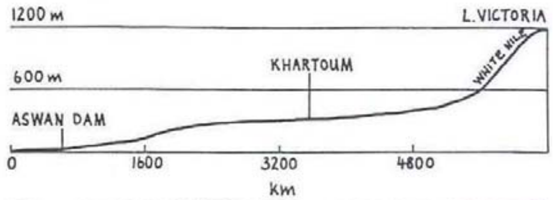
(E)



(F)

Direction: A group of young travelers is making a journey down the White Nile. They make notes as they travel. Below are three pages from their notebook. They are not in order. Based on information below, find the place each note indicates and write grid reference as (X, Y) format. **[Question 8-9]**





Another river flows into this one. We are close to a large city. The height of the land is about 300 metres. Further upstream there was a dam.

Grid reference: (4 , 9)

The river sweeps in a large bend to the west. There are fertile fields on either side. Up stream was a town sited where another river joined this one.

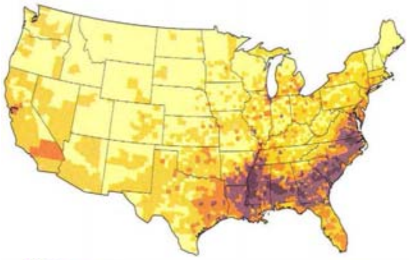
Grid reference: (,)

We are high up, probably about 1200 metres above sea level. We are close to a huge lake. North of us there is another large lake. The river flows quickly here.

Grid reference: (,)

Direction: Based on maps below, find maps having spatial correlations. **[Question 10]**

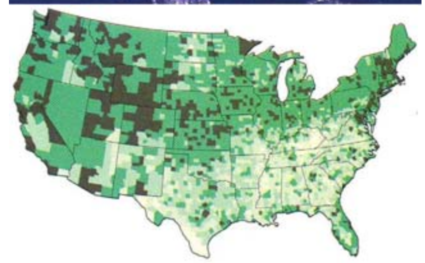
(1)



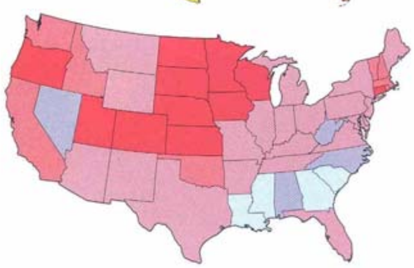
(2)

(3)

(4)

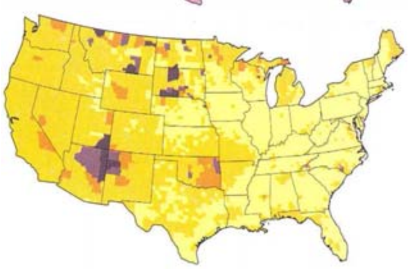


(5)



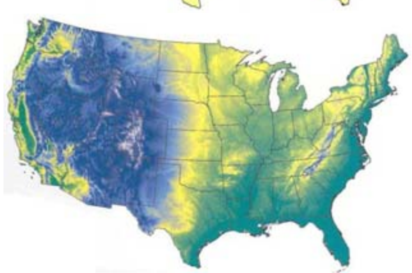
(6)

(7)



(8)

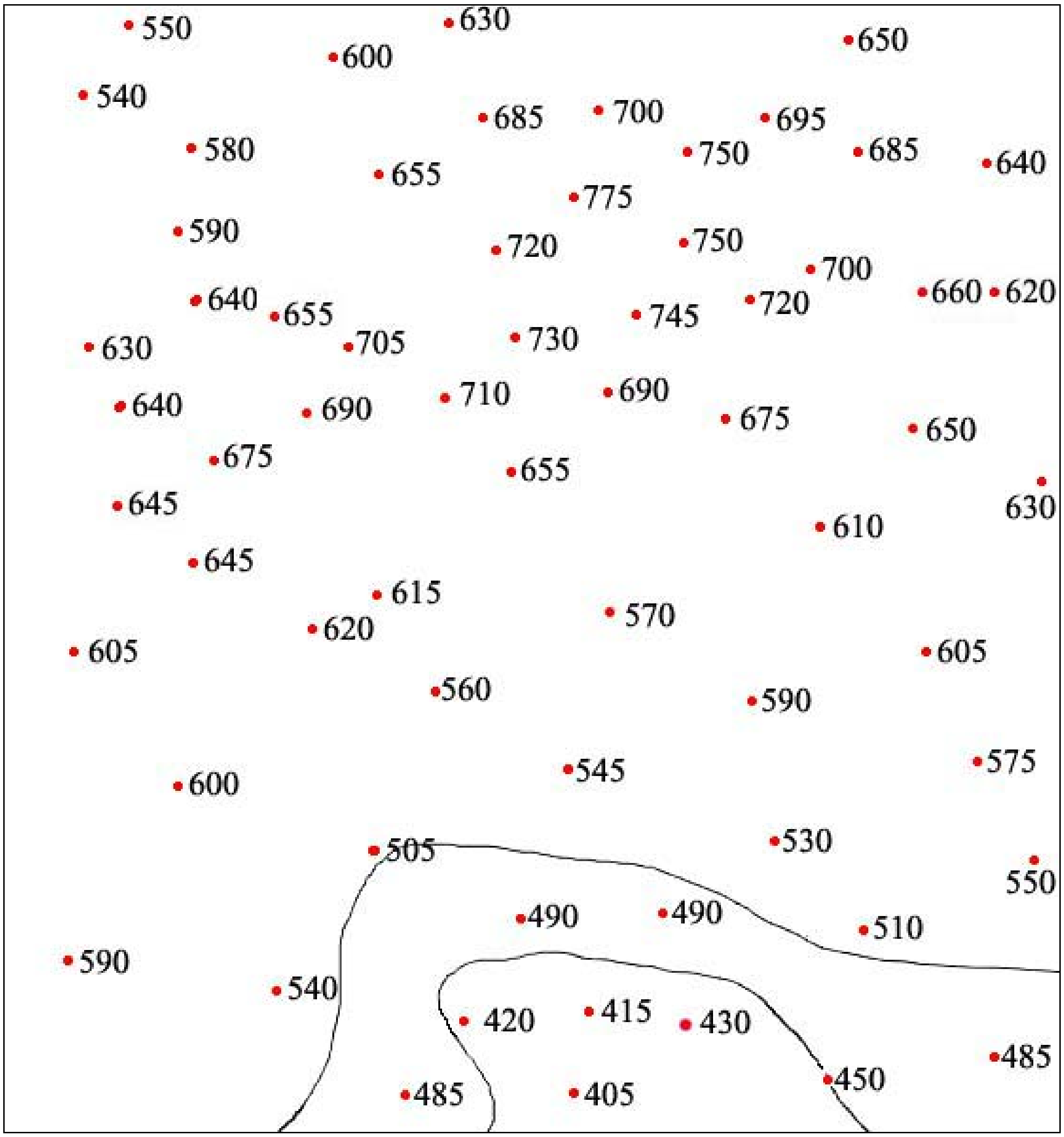
(9)



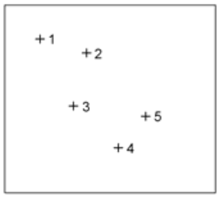
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)									
(2)									
(3)									
(4)									
(5)									
(6)									
(7)									
(8)									
(9)									

[10] Choose best 5 spatial correlations and mark (√) on the un-shaded columns.

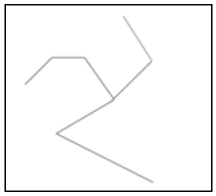
Direction: The values below are indicating elevation of each point. Based on the elevation data, create contour lines. The contour interval should be 50 feet. The lowest contour line is 400 feet. In this way your contour intervals should run 400, 450, 500…
[Question 11]

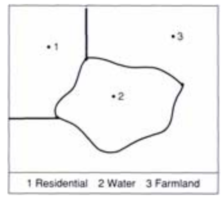


Direction: Spatial information can be displayed based on Point, Line(Arc), Area(Polygon), and Raster(lattice). Based on the sample question below, classify the following spatial data. **[Question 12-17]**



Point


Line (Arc)



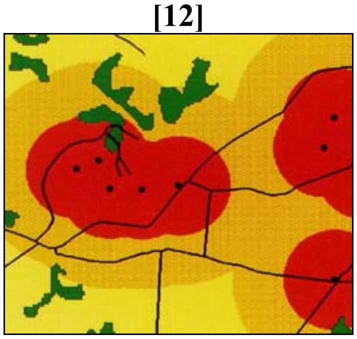
Area (Polygon)

Raster (lattice)

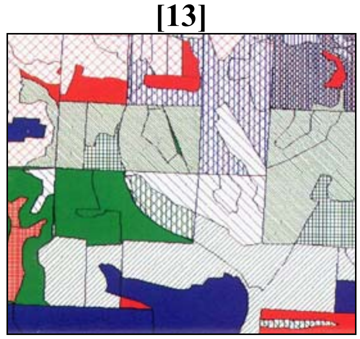
[Sample Question]

[√] Point [√] Line [ ] Area [ ] Raster

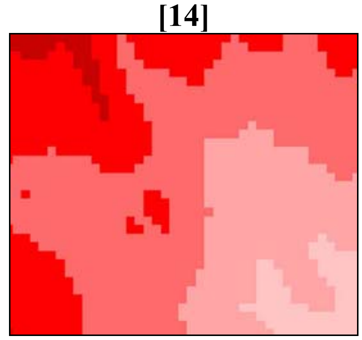
[12]



[13]


Land Use

[14]


Elevation

[15] River channels and their basins in Brazos County.
[16] Texas A&M University shuttle bus route in College Station.
[17] Surface elevation recorded on a 30-meter horizontal grid.

Please mark (√) on your answer

	Point	Line	Area	Raster
[12]	[ ]	[ ]	[ ]	[ ]
[13]	[ ]	[ ]	[ ]	[ ]
[14]	[ ]	[ ]	[ ]	[ ]
[15]	[ ]	[ ]	[ ]	[ ]
[16]	[ ]	[ ]	[ ]	[ ]
[17]	[ ]	[ ]	[ ]	[ ]

APPENDIX 2

Sketch Map Test (Pre-Test)

This questionnaire will not affect your grade in this class, and will be used only for the purpose of the research.

1. Name:
2. Gender: ☐ M / ☐ F
3. Age:
4. ☐ Freshman / ☐ Sophomore / ☐ Junior / ☐ Senior / ☐ Graduate
5. Major:
6. How long have you lived in Bryan/College Station?

   6-1. If you don’t live in Bryan/College Station, skip this question.

7. What is your usual transportation mode? You can check more than one.

   ☐ Car / ☐ Motorcycle / ☐ Shuttle Bus / ☐ Bicycle / ☐ Walk

8. Have you ever taken a GIS course? : ☐ Yes / ☐ No

   8-1. If you “Yes”, which GIS course?
   ☐ Geog 332 (Thematic Cartography)
   ☐ Geog 361 (Remote Sensing in Geosciences)
   ☐ Geog 390 (Principles of Geographic Information Systems)
   ☐ Geog 475 (Advanced Geographic Information Systems)
   ☐ Others ( )

9. Have you ever been to BestBuy? : ☐ Yes / ☐ No

   9-1. If you “Yes”, how often do you go there? (times per a month)

10. Have you ever been to HEB? : ☐ Yes / ☐ No

    10-1. If you “Yes”, how often do you go there? (times per a month)

11. Have you ever been to Hollywood Movie 16? : ☐ Yes / ☐ No

    11-1. If you “Yes”, how often do you go there? (times per a month)

A friend of yours is coming to visit you in College Station. Unfortunately you cannot show him/her around town. Draw a map to help your friend find some useful places. Your map should include the O&M building, Best Buy, HEB, and Hollywood movie 16. Show as much as detail as you can.

Sketch Map Test (Post-Test)

This questionnaire will not affect your grade in this class, and will be used only for the purpose of the research.

1. Name:

2. Have you ever been to Barns & Noble? : ☐ Yes / ☐ No

   2-1. If you "Yes", how often do you go there? (times per a month)

3. Have you ever been to Target? : ☐ Yes / ☐ No

   3-1. If you "Yes", how often do you go there? (times per a month)

4. Have you ever been to Sam's Club? : ☐ Yes / ☐ No

   4-1. If you "Yes", how often do you go there? (times per a month)

A friend of yours is coming to visit you in College Station. Unfortunately you cannot show him/her around town. Draw a map to help your friend find some useful places. Your map should include the O&M building, Barns & Nobles, Target, and Sam's Club. Show as much as detail as you can.

VITA

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